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Proposal of a Company BIM Guide in alignment with ISO 19650

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

SeyedehAida Mirniazmandan

RESUMO

A adoção e implementação do BIM têm vindo a aumentar devido aos seus benefícios durante a fase de conceção, construção, e operação dos projetos de construção. Melhorar a gestão dos dados do ciclo de vida, melhorar a qualidade e poupar nos tempos e custos são apenas algumas das vantagens de uma implementação do BIM.

O elevado volume de informação que precisa de ser produzido, coordenado e comunicado durante o ciclo de vida das instalações, realça a importância de uma gestão eficiente da informação. O aumento da difusão da tecnologia BIM junto com a necessidade de gestão estruturada dos dados levou, consequentemente, à proliferação de publicações centradas no BIM. Autoridades governamentais, associações industriais, comunidades profissionais e instituições académicas têm vindo a desenvolver documentos de orientação centrados no BIM para promover a compreensão do BIM, facilitar a gestão da informação e normalizar a implementação do BIM. Estes documentos BIM disponíveis ao público contêm diretrizes, protocolos e requisitos que se centram em produtos, processos e fluxos de trabalho BIM para minimizar as barreiras à implementação da tecnologia BIM.

Apesar da variedade e multiplicidade destes documentos, existe ainda a necessidade de um documento de orientação que seja simultaneamente descritivo e instrutivo, com recomendações estratégicas, de gestão e técnicas para criar um quadro de apoio às empresas em projetos BIM. Este é também o caso da BIMMS - BIM Management Solutions, uma empresa internacional de consultoria sediada em Portugal, que está disposta a evoluir na abordagem sistemática do BIM nos seus projetos. Portanto, esta investigação em colaboração com BIMMS visa normalizar a aplicação BIM e alcançar um fluxo de trabalho personalizado para a gestão da informação gerada ao longo de todo o ciclo de vida de uma instalação.

Para propor um guia BIM eficiente e bem estruturado, foi realizada uma extensa recolha dos documentos de orientação BIM existentes desenvolvidos por diferentes organizações e universidades, e foram determinadas as suas semelhanças e deficiências. O guia BIM proposto contém um conjunto de orientações, definições e procedimentos para uma prática BIM bem sucedida na organização. O primeiro resultado imediato do BIMMS BIM Guide é ajudar os indivíduos recém-chegados ao BIM a compreenderem melhor os fundamentos do BIM. Além disso, este documento ajudará todos os atores envolvidos num projeto a conhecerem as estratégias BIM da empresa e a produzir, divulgar e receber dados num formato consistente para obter melhores resultados.

O guia BIM proposto segue as últimas normas ISO sobre gestão da informação, ISO 19650-1 e ISO 19650-2 que fornecem um quadro comum para a colaboração e gestão da informação ao longo do ciclo de vida do projeto. A utilização de terminologias e abordagens comuns potencia o Guia BIM a ser internacionalmente credível e reconhecido.

Palavras chave: Guia BIM, Implementação BIM, ISO 19650, Manual BIM, Norma BIM.

ABSTRACT

BIM adoption and implementation have been escalating due to its benefits during the design, construction, and operation phase of the construction projects. Enhancing lifecycle data management, improving quality, and saving time and costs are just some of the advantages of a BIM implementation.

The high volume of information that needs to be produced, coordinated, and communicated during the facility lifecycle, highlights the importance of efficient information management. Increasing coverage of BIM technology and the need for structured data management has consequently led to the proliferation of BIM-focused publications. Government authorities, industry associations, communities of practice and academic institutions have been developing BIM-focused guidance documents to promote BIM understanding, facilitate information management and standardise BIM implementation. These publicly available BIM documents contain guidelines, protocols and requirements that are focused on BIM deliverables, processes, and workflows to minimize the barriers for the implementation of BIM technology.

In spite of variety and multiplicity of these documents, there is still a need for a guideline document that is both descriptive and instructive with strategic, managerial, and technical level recommendations to create a framework for supporting companies in BIM projects. This is also the case for BIMMS - BIM Management Solutions, an international consultancy company based in Portugal, that is willing to evolute on the systematic approach to BIM on its projects. Therefore, this research in collaboration with BIMMS aims to standardise BIM application and achieve a customized workflow for management of information generated over the entire lifecycle a facility.

To propose an efficient and well-structured BIM guide, an extensive research of existing BIM guidance documents developed by different organisations and universities was conducted, and their commonalties and deficiencies were determined. The proposed BIM guide contains a set of guidelines, definitions, and procedures for successful BIM practice in the organisation. The first immediate outcome from the BIMMS BIM Guide is to assist individuals new to BIM to better understand the BIM fundamentals. Furthermore, this document will assist all actors in a project to be aware of the company BIM strategies and produce, release, and receive data in a consistent format to have better project outcomes.

The proposed BIM guide follows the latest ISO standards on information management, ISO 19650-1 and ISO 19650-2 that provide a common framework for collaboration and information management over the project lifecycle. Utilising common terminologies and approaches would assist the BIM Guide to be internationally credible and recognisable.

Keywords: BIM Guide, BIM Guideline, BIM Implementation, BIM Manual, ISO 19650

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1. INTRODUCTION

1.1. Overview

Building Information Modelling (BIM) is "*a business process for generating and leveraging building data to design, construct and operate the building during its lifecycle. BIM allows all stakeholders to have access to the same information at the same time through interoperability between technology platforms*" as defined by the US National Institute of Building Sciences (NIBS, 2015). BIM provides professionals in the AECO industry with the insight and tools to plan, design, construct, and manage buildings and infrastructures more efficiently. BIM is at the heart of the ways in which the building design and construction process can adapt to rising demands for increased complexity, faster development, improved sustainability, lower costs, and more effective and efficient building operation and maintenance. Traditional practice is not able to respond to these pressures (Sacks et al., 2018).

However, there are still several challenges and barriers to BIM adoption and implementation and several studies have discussed these obstacles. Bui et al. (2016) investigated the barriers preventing BIM implementation in developing countries and they found the lack of standards and specialists are among the main issues. Also, Ahmed et al. (2018) pointed out, in their research on BIM performance in AEC companies, the absence of guidance for organisations as a hinder for adopting and implementing BIM in the organisations. In another study, Jamal et al. (2019) categorised the most prominent BIM barriers into four BIM factors of People, Technology, Process and Policy. They found out, from surveying the BIM industry specialists, that the lack of skilled BIM workforce and unfamiliarity with BIM within the industry are the most impactful barriers of BIM implementation. As Hamma-adama, Kouider, and Salman (2020), Leśniak, Górka, and Skrzypczak (2021) concluded from their extensive research, lack of standardization and protocols, and lack of expertise (within the organizations and project team) are among the most significant barriers against BIM adoption around the world.

To overcome these obstacles, several documents containing BIM protocols have been published indicating how the service providers should use BIM and maximise the benefits of this technology. Adopting protocols will create a shared vision of project delivery processes and increase the consistency of processes and quality of BIM information and deliverables for involved parties (Kassem et al., 2014). There are several organizational, procedural, and technical issues that must be addressed in BIM protocols. The BIM guidance documents explain or simplify aspects of the BIM implementation by providing detailed steps or conditions like workflows, plans and instructions.

1.2. Objectives

Taking advantage of this study being developed in collaboration with a company, this was an opportunity to study and compare the existent literature and to propose a new document, tailormade to a daily practice of BIM applications.

BIMMS - BIM Management Solutions is an international consultancy company located in Portugal, based in the AECO industry focused in helping partners to implement BIM and data solutions within their projects.

This company supports this research aiming to achieve a practical guide for BIM practice in compliance with ISO 19650. "*The ISO 19650 series is an international standard of good practice. It defines information management principles and requirements within a broader context of digital transformation in the disciplines and sectors of the built environment*" (UK BIM Alliance, 2019).

The practical BIM Guide comes in response to the BIMMS company needs to possess a comprehensive manual to be used in its projects in which all the operational areas of BIM practice in the organization are explained. This practical document provides technical level recommendations. However, it also contains managerial and tactical instructions that can be common to the BIM Execution Plan. This BIM Guide is a living document that contains a defined set of procedures, guidelines, and requirements for the practice of BIM in the organization. This document is intended to evolve over time to meet the needs for multiple building types and clients. It stablishes a process for structured BIM adoption in the company´s projects to better understand the project and improve decision making.

The main purpose of organizational BIM guideline documents is to establish working methods for project participants (Sacks, Gurevich, and Shrestha, 2016) and put all the collaborators on the same page about the methodologies and protocols that should be applied in the company's processes.

The mission of the BIMMS BIM Guide is to assist the company to leverage all individuals for a better understanding of BIM fundamentals. This manual ensures that all the involved parties will produce, release, and receive data in a consistent format. This will improve coordination among all functional groups and foster an efficient and effective workflow.

1.3. Research Methodology

This study is a direct response to a practical issue raised by this international BIM consulting company BIMMS - BIM Management Solutions aiming the development of a custom-made document for the organization level BIM guidance.

The research is based on previously published guidance documents by academic institution, government bodies, and industry organizations. The detailed benchmarking of the published documents provided a strong basis for the development of BIMMS BIM Guide. Also, meetings with company's managers and coordinators, and questionnaire survey to collect the employees and experts' opinions provided an overview of their expectations of a practical BIM guide. The research flow to develop the final BIM Guide is shown in Figure 1.

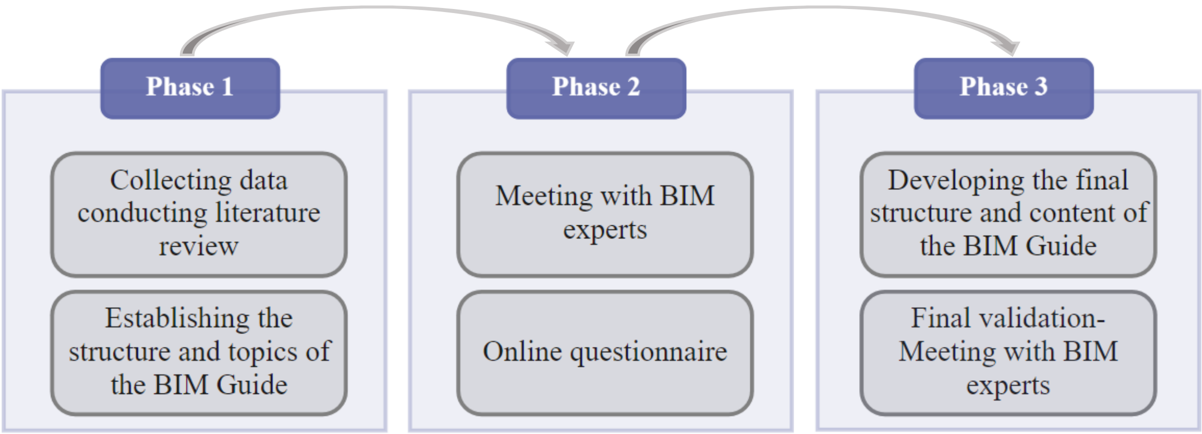

Figure 1 - Research methodology

The current dissertation is a follow-on to the dissertations of previous BIMA+ students, Terrosi (2020) and Fontana (2020), and it consolidates and expands the processes developed for the mentioned dissertations.

1.4. Structure of the Research

This dissertation is organized into eight chapters as illustrated in Figure 2.

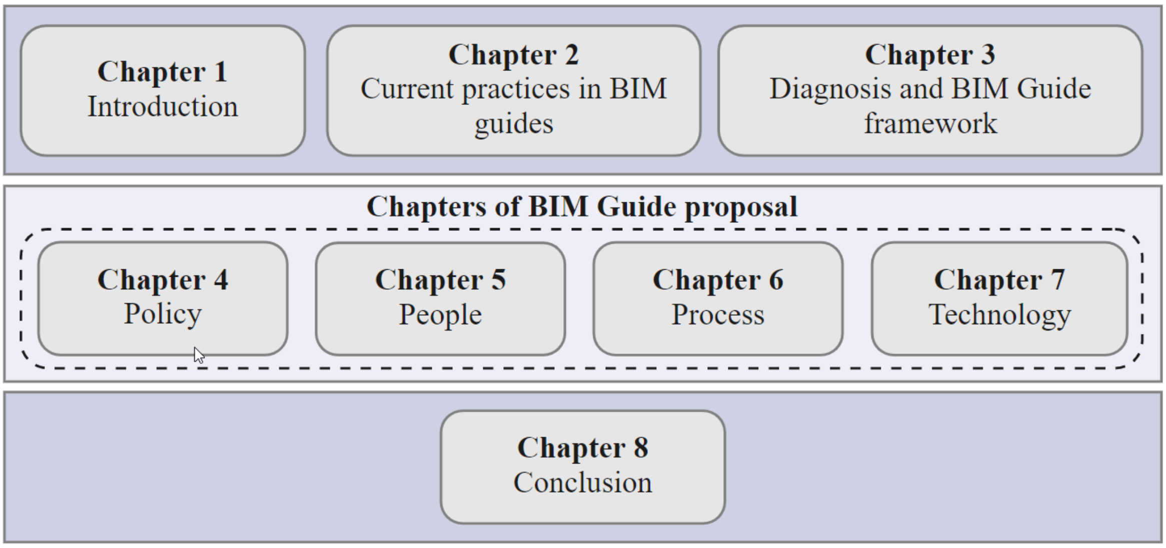

Figure 2 - Dissertation structure

Chapter 1 gives a general overview of the concept of BIM and BIM adoption procedure. It also outlines research objectives, research methodology, and dissertation structure.

Chapter 2 contains a literature review about the state-of-the-art BIM guides and benchmarking of the reviewed guides.

Chapter 3 comprehends the justifications for the structure of the proposed BIM Guide and validation of the work executed through the meeting with the BIM specialist partner company and questionnaire distributed among professionals in the company. It also includes the introduction for the BIM Guide that begins in the following chapter.

Chapters 4 to 7 comprises the BIMMS BIM Guide proposal. It starts with the first topic of the BIM Guide in chapter 4, “Policy”. It continues with the second topic of the BIM Guide in chapter 5, “People”. Chapter 6 displays the third main topic of the BIM Guide, “Process”. Finally, the BIM Guide concludes in chapter 7 with the topic of “Technology”. To explain the choices made in the BIM Guide and/or provide background, the footnotes are made in the dissertation. This ensures that the guidelines are not mixed with the explanation provided for clarification. Therefore, the BIM Guide is presented in the main text of the chapters 4 to 7, and the footnotes give complementary explanations and comments.

Chapter 8 includes the last stage of validation of the work by meeting with the BIM specialists in the company, final considerations, and remarks along with suggestions for future studies.

2. CURRENT PRACTICES IN BIM GUIDES

BIM implementations have accelerated in recent years, as more government agencies and non-profit organizations from all over the world have adopted BIM in their projects and published different BIM standards and guidelines (Cheng and Lu, 2015). These publications encapsulate extensive BIM-focused knowledge and represent significant domain expertise (Kassem, Succar, and Dawood, 2015). Many governments, research and academic institutions, and industry bodies have introduced BIM guidelines to strengthen BIM practice.

The documents containing BIM guidelines do not have a clear and consistent definition in all resources. ISO/TS 12911 defines BIM guidance document as a" document *that aids users in achieving their intended results through the use of BIM*" (ISO/TS 12911, 2012). These kinds of documents are developed for a variety of purposes at different levels as illustrated in Figure 3. In terms of application scope, they are commonly categorised into international, national, project, and facility levels. As the scope of the application is narrowed, the level of detail increases. Project or facility-level BIM guides are more detailed than national guides. These disparities come as a result of the various organizations' business contexts, objectives, and scopes.

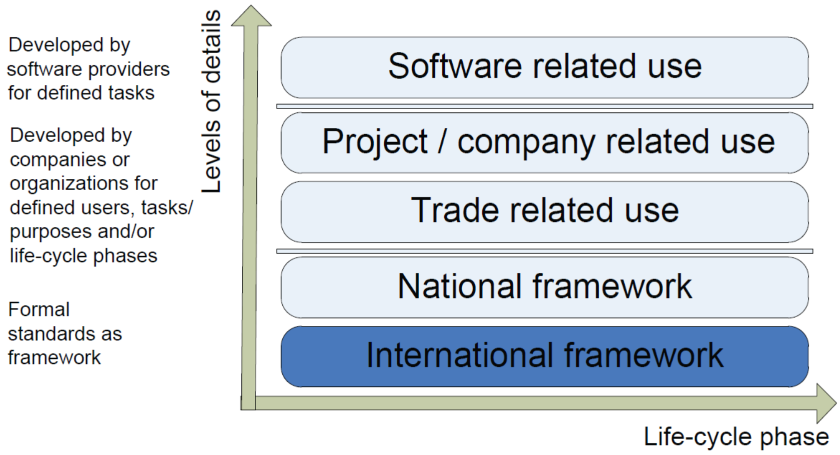

Figure 3 – BIM guidance provided at different levels (ISO/TS 12911, 2012)

A Company BIM Guide demonstrates how BIM is implemented in this organization. It leverages all the individuals and experiences in order to systematically have a common approach to the BIM processes on the several departments. It contains some direct step-by-step instructions and other more strategic points. On a scale of practicality, the Company BIM Guide should be more on the application side despite having other areas that could be more strategic, tactical, and managerial. Thus, on a decrescent scale from general strategy to specific application, it might be found International Standards, then National Guidelines, then Association Guidance, then the Company BIM Guide, and at last a Project-oriented BIM Execution Plan, that could have common parts with the Company Guide.

These documents even have different titles. ISO/TS 12911 (2012) mentions guide, guideline, manual, handbook as titles for the BIM guidance document. The most used titles for the published guidance documents are guide, guidelines, manual, protocol, requirements, handbook, standard, mandate, and project specifications. These terms are used with the BIM prefix and most of these are interchangeable.

As an example, Kassem et al. (2014) defined BIM protocols as documents or instructions in either textual or graphical format (for example process maps or flowcharts), paper or digital format that provide detailed steps or conditions to reach a goal or deliver a measurable outcome.

In order to propose a practical organisational BIM guide for BIMMS, it is beneficial to investigate the existing documents on the subject. By studying the most recent BIM guidelines, it is possible to devise the categories and topics that need to be covered in the new BIM Guide.

2.1. Reviewed Documents

The number of BIM guidance documents has been increasing exponentially over the past decade. For this study, a set of documents from international sources has been compiled and reviewed. All of these documents are freely available online. At the initial stage of the research, a wide range of resources was collected primarily from the BuildingSmart 'BIM Guide Project' database that listed 126 BIM documents as of July 2021 (BuildingSmart, 2021a) to develop a common framework for BIM guides. These documents were reviewed and some analysis criteria for identification of a specific set of these documents were devised. The documents that failed to fit the analysis criteria were removed.

The criteria for document selection:

1. The first criterion for the selection of the final list of resources for detailed review was their publishing date, that was considered from 2012 onward, to cover the most recent publications in the fact-paced BIM world.
2. The other criterion was the document type, in a way to be both descriptive and instructive. Many of the guidelines available only cover the strategic and managerial parts of the BIM process so that are not selected for review as the guide should include also hands-on instructions.
3. Also, the selected document must cover the various topics and not focused only on limited issues, for example some guides are focused on BIM objects, quality check or other specific topics so that they are excluded from the list. A threshold level of 5 was applied; the guides that include at least 5 topics could be selected.

Eventually, a selection of 19 guides published in 9 different countries was selected for analysis from the 126 documents listed by BuildingSmart (2021a) and other sources available online. Figure 4 shows the timeline for the selected BIM guides that are reviewed in detail in this study.

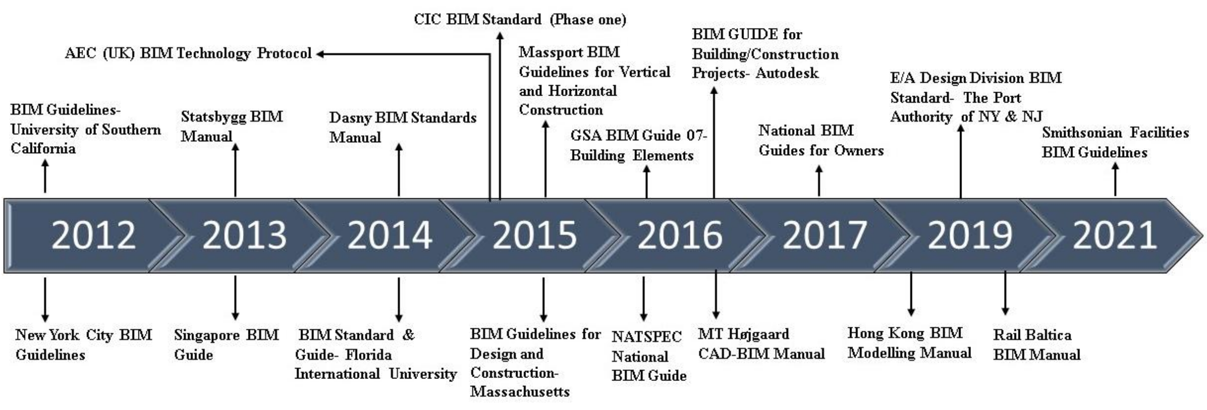

Figure 4 – The reviewed BIM guides timeline

Table 1 – The reviewed BIM guides information

	Document Name	Document short name	Publishing Organization	Organization Type	Country	Year
1	**BIM Guidelines**	USC	University of Southern California Capital Construction Development and Facilities Management services	Academic institution	US	2012
2	**BIM Guidelines**	New York	New York City Department of Design+ construction	Government construction authority	US	2012
3	**Statsbygg BIM Manual**	Statsbygg	Statsbygg	Government construction authority	Norway	2013
4	**Singapore BIM Guide**	Singapore	Building and Construction Authority	Government construction authority	Singapore	2013
5	**Dasny Building Information Model (BIM)Standards Manual**	Dasny	Dormitory Authority State of New York	Government construction authority	US	2014
6	**BIM Standard & Guide**	FIU	FIU- Florida International University	Academic institution	US	2014
7	**BIM Guidelines for Design and Construction**	Massachusetts	Commonwealth of Massachusetts	Government construction authority	US	2015
8	**BIM Guidelines for Vertical and Horizontal Construction**	Massport	Massachusetts Port Authority-Massport	Government construction authority	US	2015
9	**AEC (UK) BIM Technology Protocol**	AEC (UK)	AEC (UK)	Industry non-profit organization	UK	2015
10	**CIC BIM Standard (Phase one)**	CIC	Construction Industry Council	Government construction authority	Hong Kong	2015
11	**CAD-BIM Manual - General Part**	MT Højgaard	MT Højgaard	Industry non-profit organization	Denmark	2016
12	**NATSPEC National BIM Guide**	NATSPEC	Construction Information Systems	National Standards Agency	Australia	2016
13	**BIM GUIDE for Building/Construction Projects**	Autodesk	Moscow Autodesk Consulting	Industry non-profit organization	Russia	2016
14	**GSA BIM Guide 07-Building Elements**	GSA	U.S. General Services Administration	Government construction authority	US	2016
15	**National BIM Guides for Owners**	NBGO	National Institute of Building Sciences	National Standards Agency	US	2017
16	**BIM MODELLING MANUAL**	DSD	Government of the Hong Kong Special Administrative Region	Government construction authority	Hong Kong	2019
17	**E/A Design Division BIM Standard**	PANYNJ	The Port Authority of NY & NJ Engineering Department	Government construction authority	US	2019
18	**Design Guidelines BIM Manual**	Rail Baltica	Rail Baltica	Industry non-profit organization	EU	2019
19	**Smithsonian Facilities BIM Guidelines**	SF	The Smithsonian Institution	Industry organization	US	2021

Table 1 presents the guides selected for the review in chronological order of publication along with information about publishing organisation and country. For this study, the document short name, as listed in Table 1 is used to refer to and cite the documents.

The scope and purposes described in each of the 19 reviewed documents are presented below.

1. **BIM Guidelines - University of Southern California Capital Construction Development and Facilities Management services (USC)**

Based on a Design Bid Build type of Contract, this document describes the Design and Construction scope of work and deliverables for employing Building Information Modelling (BIM) on new USC construction projects, major renovations, and other projects as required by USC (USC, 2012).

2. **BIM Guidelines - New York City Department of Design+ construction (DDC)**

The DDC BIM Guide establishes principles for the uniform development and application of BIM across a wide range of building types and municipal agencies. This guidance will also be valuable for any agency or organization that wants to use BIM for public projects in New York City but doesn't have its own set of standards. The goal of the guidance is to ensure that all New York City Public Buildings projects use BIM in the same way. The BIM guide considers the model's end-use for a variety of client agencies, allowing qualified and authorized client agency representatives to assess how the BIM can help them with their ongoing building operation and maintenance protocols, and tailor their agency requirements and standards to take advantage of the enhanced capabilities provided by BIM for building O&M. In support of each agency's objective, this BIM Guide will also support client agency design standards (DDC, 2012).

3. **Statsbygg BIM Manual – Statsbygg (SBM)**

The goal of SBM is to define Statsbygg's requirements for Building Information Models (BIM) in the open Industry Foundation Classes (IFC) format, including both generic and discipline-specific specifications. During operational projects, the requirements may be supplemented or changed. Design teams, client project and facilities managers, and domain practitioners working in BIM processes are the major target audiences for SBM. SBM may also be useful for providing recommendations to software application developers (SBM, 2013).

4. **Singapore BIM Guide - Building and Construction Authority (Singapore)**

The Singapore BIM Guide Version 2 tries to define the many possible deliverables, procedures, and persons / experts involved when Building Information Modelling (BIM) is utilized in a construction project. Users can use the Guide to define the roles and responsibilities of project members when using BIM in a construction project. The roles and responsibilities are then documented in a BIM Execution Plan that the Employer and project members must agree on (Singapore, 2013).

5. **Dasny Building Information Model (BIM)Standards Manual - Dormitory Authority State of New York (DASNY)**

The DASNY BIM Standards Manual will establish rules to ensure that Design Professionals throughout New York State develop, disseminate, and receive data in a standardized format for a variety of building types and clients. This will ensure that data is exchanged efficiently between disciplines and that each discipline's model is compatible (s). DASNY's BIM practice now uses a number of Autodesk tools. In general, the DASNY BIM Standards Manual will use terminology and references specific to Autodesk-based software applications. The DASNY BIM Standard establishes a framework for the management of BIM projects. The main objectives of this structure are to increase collaboration between all DASNY functional groups and their Design Professionals, as well as to establish BIM projects in a way that allows for continued usage of this electronic information after the initial contract is completed (DASNY, 2014).

6. BIM Standard & Guide - Florida International University (FIU)

Florida International University (FIU) has created this BIM Standard to define the Design and Construction BIM scope of work and the university's operational intent for data usage when using BIM on new FIU Construction projects, refurbishment projects, and other projects in order to promote the use of Building Information Modelling (BIM) 3D technology. The University hopes that by developing this Standard, they will be able to continue to encourage industry adoption of building information modelling on both a professional and academic level, as well as allow the University's Facility Management Department to realize cost savings from BIM by making it easier for management personnel and future design and construction teams to access information about the buildings from the technology (FIU, 2014).

7. BIM Guidelines for Design and Construction - Commonwealth of Massachusetts (DCAMM)

The DCAMM Building Information Modelling (BIM) Guide specifies requirements for the BIM services, project execution, and submissions. For all phases of DCAMM projects, BIM is employed. The Program Designer can now finish the Study Phase and move on to final design under current law. BIM "best practices," Lean project techniques, industry, and DCAMM data standards are all incorporated into the recommendations. All of this is part of DCAMM's stewardship approach to maximize BIM's analytical and information production potential for project submissions and facility lifecycle data (DCAMM, 2015).

8. BIM Guidelines for Vertical and Horizontal Construction - Massachusetts Port Authority (MPA)

This BIM Guide for Vertical and Horizontal Construction was produced by the Massport Capital Programs and Environmental Affairs Department for design, construction, civil, and facilities professionals working on MPA projects. It describes the project model rules and standards to be used in a BIM/Lean collaborative environment. The guide's purpose is to provide uniformity in MPA's numerous service providers' procedures and BIM development across a variety of project types (MPA, 2015).

9. AEC (UK) BIM Technology Protocol - AEC (UK)

The AEC (UK) BIM Technology Protocol v2.1 builds on the frameworks outlined by UK (and relevant International) protocols, specifications, and documents, along with existing, established internal company procedures, to provide coherent platform-independent guidance for project BIM technologies implementation and use. The goals are to: 1. Increase production efficiency by taking a coordinated and consistent approach to achieving the UK Government's BIM maturity levels. 2. To establish best practices for ensuring the supply of high-quality data and consistent data exchange across a whole project. 3. Ensure that digital BIM files are properly structured so that all project participants can work efficiently in a collaborative setting (AEC (UK), 2015).

10. CIC BIM Standard (Phase one) - Construction Industry Council (CIC)

The CIC BIM Standards lay forth a method for implementing BIM on construction and infrastructure projects. The CIC BIM Standards are meant to be utilised to define the scope of work for a BIM process, the project participants' responsibilities, and the deliverables from the BIM process for the project's and owner's overall benefit (CIC, 2015).

11. CAD-BIM Manual - General Part - MT Højgaard

This document explains how MT Hjgaard constructs and manages BIM models and drawings. The processes outlined in this document are not expected to be used as guidelines, but rather as a series of instructions to be followed. This manual will not be used as a Revit program manual. As a result, the document requires a basic understanding of Revit (MT Højgaard, 2016).

12. NATSPEC National BIM Guide - Construction Information Systems (NATSPEC)

The purpose of the National BIM Guide is to help clients, consultants, and stakeholders articulate their BIM requirements in a consistent manner across the country. As a result, there will be less confusion and duplication of work. The guide is based on the VA BIM Guide, and the goal behind it is to save as much of the original document as feasible (NATSPEC, 2016).

13. BIM GUIDE for Building/Construction Projects – Moscow Autodesk Consulting (Autodesk)

This guide is intended to assist companies participating in the generation and use of BIM models for construction projects, with an emphasis on adapting best practices for optimum use of Revit®, AutoCAD®, Civil 3D®, and Navisworks®. This Guide does not, however, prohibit the use of any alternative software tools. The document does not cover the complexities of information model development, procedures, or needs for certain design disciplines. It gives guidelines and procedures for the creation of information modelling standards documents (Autodesk, 2016).

14. GSA BIM Guide 07- Building Elements - U.S. General Services Administration (GSA)

Building Elements, GSA BIM Guide 07, outlines the building information modelling (BIM) delivery requirements to support the technical tools and business processes, as well as to ensure that GSA receives and manages the same set of information for all our buildings, obtaining all of the data needed to execute facility and asset management for all of our buildings, as well as receiving and managing building data in a consistent, open-standard manner. This is accomplished by GSA BIM Guide 07, which specifies the data elements that must be included in a GSA building information model (GSA, 2016).

15. National BIM Guides for Owners - National Institute of Building Sciences (NBGO)

The Owner and the rest of the Project BIM Team, which can include planners, constructors, facilities managers, and subcontractors, as well as designers, can use this Guide as recommendations for processes, standards, and deliverables for a BIM-enabled project. The Owner should use the guidelines in this Guide to build customized BIM project requirements based on the project's unique and individual needs, which the Project BIM Team could then follow and apply to increase facility value (NBGO, 2017).

16. BIM Modelling Manual - Government of the Hong Kong Special Administrative Region (DSD)

The BIM Modelling Manual provides guidelines for the process of generating BIM models for drainage / sewerage facilities / networks that are controlled and maintained by the Drainage Services Department (DSD). This Manual should be followed with the goal of (a) producing standardized, high-quality, and interoperable BIM models/deliverables, (b) encouraging the use of BIM models throughout the project life cycle, (c) facilitating collaboration, communication, and information/data, (d) facilitating an efficient and effective workflow, and (e) allowing asset data in BIM models to be transferred to existing asset management (AM) and facility management (FM) systems (DSD, 2019).

17. **E/A Design Division BIM Standard - The Port Authority of NY & NJ Engineering Department (PANYNJ)**

The Building Information Model (BIM) Standard Manual of the Port Authority of New York and New Jersey (PANYNJ) outlines the processes and procedures for preparing and submitting BIM Models for PANYNJ projects. The BIM Standard Manual for the Port Authority of New York and New Jersey assures that the Engineering Department produces, releases, and receives data in a consistent format. This will ensure efficient data exchange between disciplines, as well as the compatibility of each discipline's model(s) with different outside consultants. This document comprises all BIM Guidelines and Requirements for the entire agency, and it is intended to provide an overview of the requirements that apply to all E/AD Stages (PANYNJ, 2019).

18. **Design Guidelines BIM Manual - Rail Baltica**

This BIM Manual establishes principles and requirements for the Supply Chain in the context of providing and exchanging "BIM" data in the form of digital models with RB Rail AS and National Implementing Bodies. Its goal is to ensure that the various deliverables created within the context of BIM digital exchanges are consistent, especially in terms of data consistency and geo-referencing. There are also special appendices or annexes for various purposes, such as templates for some of the deliverables, in this document. This version of the document is designed for all Rail Baltica project contractors and companies (Rail Baltica, 2019).

19. **Smithsonian Facilities BIM Guidelines- The Smithsonian Institution (SF)**

Smithsonian Facilities office is responsible for both in-house design efforts and administration of repair, renovation and new construction projects for the museums and other facilities. The goal of this document is to convey to architecture, engineering, and construction consultants the important processes, roles, and details for BIM development for SF projects. This document contains the appearance of drawings, BIM element standards and symbols, and deliverable requirements (SF, 2021).

2.2. Topics for Content Analysis

In general, the selected documents cover a broad spectrum of topics. It is mainly related to the organizations that have published the guides and their requirements. However, several commonalities were observed, and some main topics are covered in many of them, although, in some documents, different terms are used to refer to the same topics. After careful review of the documents, 17 topics were selected for detailed review in this work, some are the main topics, and some appeared as a sub-topic in the studied resources.

The criteria for selecting these topics were their significance to the company BIM application and/or the consistent presence of the topics in most of the analysed documents. The inclusion of all the range of subjects from strategic to more technical was another criterion that was considered.

The 17 topics selected for the review are as follows:

1. **Modelling Requirement and Procedures**
   This topic in the resources generally contains the procedures and steps required for modelling in the software and how to set up modelling requirements to ensure high quality models. A few of the resources also provide specific modelling guidelines for each discipline.
2. **Standards and Classifications**
   Following agreed standards and classifications throughout the project is fundamental in achieving effective information management. However, few of reviewed documents mention the topic of standards and classification.
3. **Naming Convention**
   In every BIM project, consistent and clearly recognisable information is critical so that many of the BIM guide documents provide guidelines for a series of important naming conventions such as file naming, folder naming, object naming and many more.
4. **Collaboration Procedures/CDE**
   From the initial stage of the project, the strategies for collaboration shall be clearly defined. Several of the resources defined collaboration frameworks and CDE strategies based on the standard of PAS 1192-2:2013.
5. **BIM Execution Plan**
   PAS 1192-2:2013 defines BIM Execution Plan often abbreviated as BEP or BxP as a "*plan prepared by the suppliers to explain how the information modelling aspects of a project will be carried out*". Many of the BIM guide resources have a section providing an overview of BEP and/or a template for the BEP to fill in at the end of the document as an appendix.
6. **Lox**
   A BIM information model is supposed to contain only necessary information required for a project, not everything. As a result, establishing the proper amount of detail for models to satisfy their objectives is crucial for project implementation efficiency. Lox is used to refer to the different LOD-related terms. However, the studied documents are mostly concerned with the concept of LOD as level of development. Many of them provide descriptions of the concept and a few numbers of them go a step forward and provide the required LOD specifications for each building element for each project stage.
7. **Software and File Format**
   In a BIM workflow, data can be produced and processed in a variety of ways, and as a result, there are a multitude of software and file formats that can be employed. The reviewed resources introduce the tools and formats that are utilised in the organisation that the guide is developed by.
8. **Folder Structure**
   An organised folder structure avoids confusion and saves tremendous amount of time especially in big and complex projects. Thus, many BIM guides provide a sample structure for setting up a folder structure.
9. **BIM Object**

BIM object is a combination 3D geometry with the data that describes that geometry. Only a limited number of the reviewed guides covered this topic in a not so detailed way. However, there are a number of published documents that specifically focus on the BIM object.

10. **BIM Roles & Responsibilities**
    To manage and implement a project properly, it is essential to define roles and responsibilities from the outset. It is an important topic that most of the reviewed resources cover and provide definitions and explanations for the required roles and function in a BIM project.
11. **Deliverables**
    The outputs that are expected from a BIM process are deliverables. The reviewed documents classify the deliverables in various ways such as dividing them based on project phase or deliverable type.
12. **COBie**
    COBie is an international standard that stands for the Construction Operations Building Information Exchange. It is used to handover product data from construction to operations. In a few of the reviewed resources, the concept of Cobie and its structure is defined.
13. **Clash Detection**
    It is the process of identifying if the building or facility elements are conflicting with each other. Clash detection is a significant part of BIM process that saves time and reduce costs in the projects so that many of the reviewed documents cover this topic, some of them in high detail.
14. **BIM Uses**
    A BIM Use is defined as "*a method of applying Building Information Modeling during a facility's lifecycle to achieve one or more specific objectives"* (Kreider, and Messner, 2013). The BIM Uses can be classified based on the objective for implementing during the project life cycle. The resources reviewed present BIM Uses in different ways, most of them classifying based on project phase, a few based on the Use type and a few other just list them.
15. **Quality Control**
    Quality checks ensures accurate and complete BIM models. Several of the reviewed documents cover this topic and some of them provided the types of checks that must be conducted during the BIM project.
16. **Presentation Styles**
    This topic is related to the final output of drawings and their appearance and to ensure their consistency and quality. A few of reviewed documents briefly provided recommendations on this subject.
17. **Software Template**
    Templates help to standardise modelling practices throughout a project or even multiple projects for an organization to ensure that the end product aligns with industry and organizational standards. Very few numbers of reviewed resources cover this topic. However, there are documents that solely focus on how to create software templates.

2.3. Collected Data and Analysis

These documents include a significant amount of specialized BIM knowledge. However, the coverage and distribution of this BIM knowledge differs remarkably across the documents. Table 2 presents the comparison matrix for the topics and BIM guides. It is to demonstrate how often the topics are included in the guides and in what degree of detail or comprehensiveness they appeared in the guides. The topics are analysed and categorised in 3 levels:

- **Mentioned** means that the topic is mentioned but not described further.
- **Detailed** means the topic is explained.
- **Highly detailed** means that the topic is elaborated on.

A score is assigned for the 3 categories of detail to further analyse the coverage of each topic in all the guides. The score are as follows; Highly Detailed=5, Detailed=3, and Mentioned=1.

Each of these 3 levels are illustrated in the matrix as shown below:

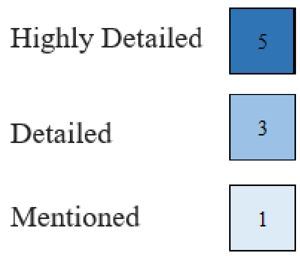

Figure 5 - The levels in the matrix

Table 2 - BIM guides and review topics comparison matrix

	Reviewed Topic / BIM Guide Name	1 Standards and Classifications	2 BEP	3 BIM Roles & Responsibilities	4 BIM Uses	5 Deliverables	6 Lox	7 Quality Control	8 Collaboration Procedures	9 Clash Detection	10 COBie	11 Folder Structure	12 Naming Convention	13 Presentation Styles	14 Software and File Format	15 Software Template	16 BIM Object	17 Modelling Procedures
1	BIM Guidelines- University of Southern California		3			3	1	1		1	3				1			1
2	New York City BIM Guidelines	1	1	1	5	3	3			1			3		1		1	
3	Statsbygg BIM Manual	1				3		3		5			3					5
4	Singapore BIM Guide		1	3	3	3		5	3									5
5	Dasny Building Information Model (BIM)Standards Manual		1			1	1			3		3	5		1		1	
6	BIM Standard & Guide- Florida International University	1	3	3	5	3	1				5	1	1		1			3
7	BIM Guidelines for Design and Construction- Massachusetts	3	3	5	5	1	3	1	3	3		3	3	1	3		1	5
8	Massport BIM Guidelines for Vertical and Horizontal Construction	1	3	3	3	1	3	1	3	1		3	3	1	1		3	3
9	AEC (UK) BIM Technology Protocol		1	3			3		3			5	5	3				5
10	CIC BIM Standard (Phase one)		1	3	3		5	1	1	1		3	3	1	1			3
11	MT Højgaard CAD-BIM Manual - General Part	1					1						3	3		3		5
12	NATSPEC National BIM Guide			5	5	3	3		3	1	1	1	1		1			1
13	BIM GUIDE for Building/Construction Projects-Russia Autodesk		3	3			5	3	3	5		3	5		3	1		5
14	GSA BIM Guide 07- Building Elements		5	1	1	1	3	5		3			3		1			3
15	National BIM Guides for Owners	3	1	1	5	3	1	1				1	1					1
16	Hong Kong BIM Modelling Manual						5	5			5	5	5	3	5			3
17	E/A Design Division BIM Standard- The Port Authority of NY & NJ		5	3	1	3	3	3	3	5		5	5		3	5		
18	Rail Baltica BIM Manual	1	3	5	5	5	3	5	5	5					5		3	
19	Smithsonian Facilities BIM Guidelines		5		3	5	3			1		1	5	5	3	3		5

The research outcome reveals how many times each topic was covered among all selected BIM guidelines and how detailed each topic was. Table 3 is the result of analysing the Table 2- comparison matrix to show the frequency of the topics across the guides and the total degree of specificity of each topic in the guides.

The degree of specificity is calculated by adding the respective scores. Regarding the 19 selected guides, the maximum specificity value for each topic can be 95. This is in the case when the topic is covered in highly detailed degree in all the 19 guides.

Table 3 - document topics and their frequency and degree of specificity in the documents

Topics	Frequency (0-19)	Frequency (Percentage)	Degree of Detail (0-95)	Degree of Detail (Percentage)
Naming Convention	16	84	54	57
Modelling Procedures	15	79	53	56
Lox	17	89	47	49
BIM Uses	12	63	42	44
BEP	15	79	39	41
BIM Roles & Responsibilities	13	68	39	41
Deliverables	14	74	38	40
Clash Detection	13	68	35	37
Folder Structure	12	63	34	36
Quality Control	12	63	34	36
Software and File Format	14	74	30	32
Collaboration Procedures	9	47	27	28
Presentation Styles	7	37	17	18
COBie	4	21	14	15
Standards and Classifications	8	42	12	13
Software Template	4	21	12	13
BIM Object	5	26	9	9

Also, the topics frequency percentage and total detail score percentage are demonstrated in the bar graph in Figure 6.

According to the outcome of the analysis, “Naming Convention” and “Lox” were mentioned the most and appeared in more than 80% of the reviewed documents. Also, “Naming Convention” and “Modelling Procedure” with more than 50% degree of specificity are the topics that covered in highest degree of detail compared to others.

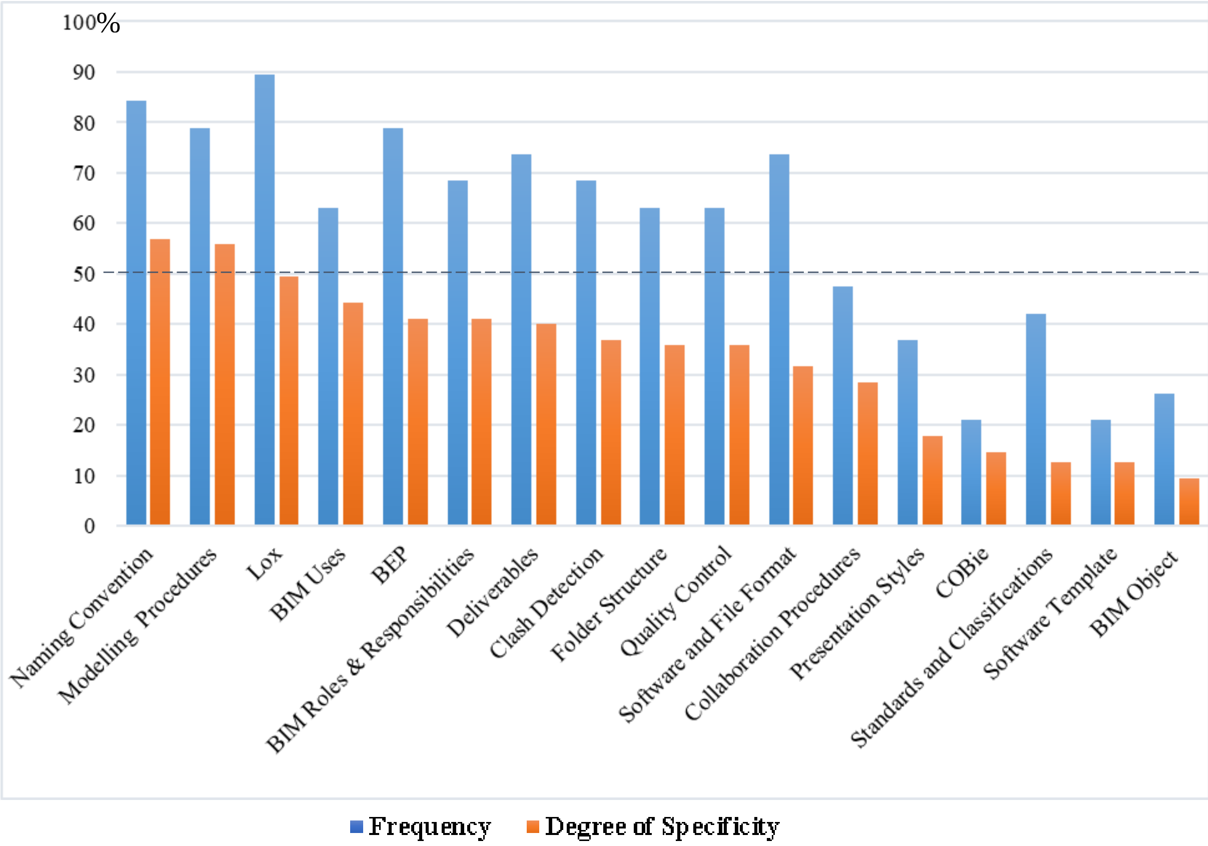

Figure 6 - The percentage of topics frequency and specificity

11 out of 17 topics appeared in more than half of the guides and it emphasises the importance of these topics to be included in the new guide. Some topics including "BIM Object" and "Software Template" only existed in less than 5 documents. This may be justified because there are published documents that solely focus on these topics, NBS BIM Object Standard is an example. Most of the guides do not cover several technical and practical topics in detail only mentioning them.

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3. DIAGNOSIS AND BIM GUIDE FRAMEWORK

This chapter addresses the process for the validation of the developed document, and the justifications for the structure of proposed BIM Guide. In this dissertation, the term BIM guide is used to refer the document developed to help company BIM users to implement BIM effectively and efficiently. The dissertation work is in response to the need of BIMMS company; therefore, its input was taking into account across all the stages of the development. For that, the dissertation outputs were validated in three major milestones parallel to the document production. The first one was during the second month of work in the form of a meeting with BIMMS board and professionals to present the dissertation outline and main topics. The second phase of validation was in the form of a questionnaire distributed among the BIMMS staff. Finally, the third stage of validation was conducted presenting the output of the final work to BIMMS board and professional. This chapter presents the first and second stages of the validation. The last stage is presented in the conclusions of this dissertation. Conducting these validation stages, a great number of valuable comments have been received along with the validating of the work.

3.1. BIM Guide Structure Justification

This explains the development approach for the main structure of the document. BIMMS BIM Guide is developed to propose guidelines and recommendations for BIM collaborative design that can be utilised by an entire supply chain to increase the efficiency and consistency of information flow and BIM deliverables. The BIMMS BIM Guide covers wide BIM requirements and standards trying to include strategic concepts, managerial processes, and operational and technical instructions.

To organize different domains of BIM knowledge into the BIM Guide, a systematic framework is desirable. Based on Kassem et al. (2014), a BIM framework is a structured theoretical construct that can assist in organizing BIM domains of knowledge and facilitate the creation of new knowledge. The framework proposed in this guide is based on the framework presented by Succar (2009) that introduced three BIM fields of policy, process, and technology in the taxonomic nodes.

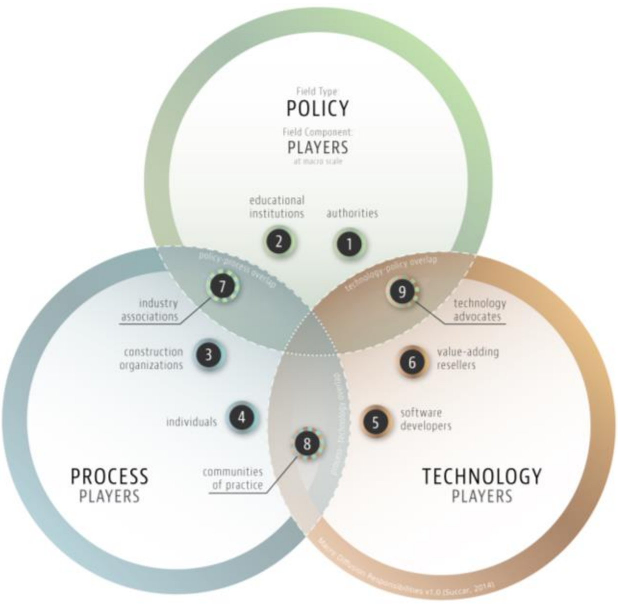


Figure 7 – BIM fields (Succar & Kassem, 2015)

Taxonomies play an important role in clarifying complex topics and facilitating understanding (Kassem, Succar, and Dawood, 2015). To organize and classify the knowledge in the BIM Guide proposal, the specialized taxonomy derived from Succar (2009) BIM fields is introduced. This taxonomy includes four main content clusters; **Policy, People, Process,** and **Technology**. The BIM Guide content taxonomy consists of content labels grouped under four domains of knowledge with specific taxonomic properties. The content begins with the Policy domain at the top of the pyramid (Figure 8), People at the second level, Process at the third level and eventually Technology domain at the bottom. The hierarchy of these four levels depicts the BIM Guide content starts from Policy with strategic concepts to the Technology with technical and operational instructions.

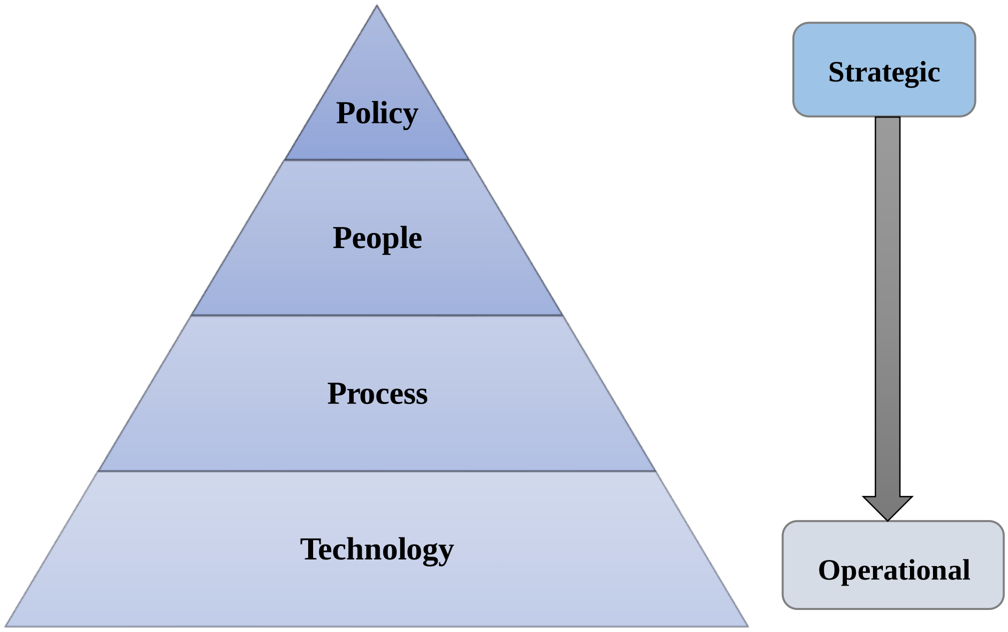


Figure 8 – BIM Guide taxonomy

The proposal for the BIMMS BIM Guide is supposed to be thorough and cover all the areas of BIM practice in the company. Thus, it is decided to cover all the 17 reviewed topics discussed in *Topics for Content Analysis* section in the proposal of the new guide. This way the BIMMS BIM Guide contains strategic, managerial, and technical guidelines to be useful for all project players throughout the project lifecycle.

To place each of the 17 topics into the four content clusters, two methods were implemented:

- First one is a system of concrete questions as criteria in a way that each topic fits to the pertinent category by positive answer to at least one of the questions. If the answer for a question is positive, the related cell is coloured in the table.
- Second method is assigning each topic to the sub-categories of each cluster, for example Policy cluster has the sub-categories of Contractual, Regulatory, and Preparatory. These sub-categories

extracted from the series of papers especially the papers by Succar (2009), Succar (2010) and Kassem et al. (2014).

As a result of responses to both methods, each topic is placed in the relevant category, although this placement is not solid, and it is arguable.

As shown in Table 4, for BEP topic as an example, both questions related to the Policy cluster are coloured and the Contractual sub-category is also coloured. Thus, it is concluded that the best placement for the BEP would be Policy category and Contractual sub-category.

Table 4 – Two methods of categorising the topics in the 4 main clusters

	Content Cluster	Criteria	BEP	Standards and Classifications	BIM Roles & Responsibilities	Software and File Format	Folder Structure	Naming Convention	Presentation Styles	Software Template	BIM Object	Modelling Procedures	BIM Uses	Deliverables	Lox	Collaboration Procedures/CDE	Quality Control	Clash Detection	COBie
Method 1	Policy	Is it a set of principles or rules to guide decision-making?	■	■															
		Is it a high-level overall plan embracing the general goals?	■																
	Process	Does it involve a series of operations conducing to an end?											■	■			■	■	
		Is exchange of information involved?											■		■	■	■		■
	People	Is it related to skills, knowledge, or training?			■														
		Is it related to organizational structure?			■														
	Technology	Is it related to the use of scientific knowledge or technical methods for practical purposes?				■	■	■	■	■	■	■	■						
		Is it a system or device used for practical purposes?				■	■	■	■	■	■	■							■
Method 2	Policy	Contractual	■											■	■		■		
		Regulatory		■															
		Preparatory																	
	Processes	Communiction														■		■	
		Infrastructure														■			
		Procuct and services											■	■	■		■		■
	People	Human resources			■														
	Technology	Software				■			■	■	■	■							
		Hardware																	
		Network					■	■											

Analysing the results extracted from Table 4, the primary categorisation of the topics was presented in the interview with BIMMS experts and At the end of the meeting, the second phase of validation consisting of a questionnaire to be distributed among all the BIMMS company staff, was discussed and approved.

Questionnaire Survey (see question 2) to ask the opinion of the BIMMS professionals about it. Conducting the interview and the questionnaire, the majority of the respondents found this classification sound and logical, and a few topics and modifications were suggested. Both the interview and the questionnaire survey have highlighted a number of key issues. The suggestions were analysed and the ones that were applicable to the objectives and structure of the guide were applied.

3.2. First Presentation for BIMMS Company Boards and Professionals

The first step of the validation process was in the form of a meeting with all the board and a BIM Manager of the company. The duration of the meeting was 1 hour and thirty minutes, and with the consent of the interviewees, it was recorded for further analysis. The structure of the meeting was as follows:

- Introduction to Dissertation´s Goals
- Presentation of main structure of the BIM Guide
- Receiving generic feedback
- Presentation of detailed Table of Contents
- Receiving specific feedback

After introducing the goals and aims of the dissertation, the second part of the presentation began with the explanation for the main structure of the dissertation (See Appendix 1). This includes the main categories, topics, and sub-topics. After presenting general overview of the BIM Guide structure, the BIMMS professionals expressed their ideas and provided suggestions. After that, the detailed table of content was introduced (See Appendix 2) and some tables and workflows related to each topic were also presented. This enables the panellists to have a clearer idea of what the content of each topic can be. In this part of presentation, we received valuable recommendations and comments as well.

Overall, the developed work till then was approved and the feedback was positive. The comments and suggestions received are listed in Table 5. For each comment, it is mentioned if the work will be changed based on that or not and the reasons for either decision.

Table 5 – The first stage validation results

Feedback	Applied?	Changes applied or justifications for sustaining as it is
The order can be different for *People* and *Process*.	No	It is decided to have concepts and definitions first in order so that *People* is better to be before *Process*.
People topic can be a part of *Process*.	No	Yes, it can. However, the definition of process is in a way that all topics can be considered as a process so that the current taxonomy of 4 categories might continue.
Lack of a topic for tracking the BIM project process.	Yes	A sub-topic has been added for progress tracking.
Lack of a topic for Metadata management or information exchange.	Yes	A sub-topic has been added for information exchange.
For *deliverables* classification, RIBA plan of work can be used, or divided based on the models- drawings- schedules- simulations	Yes	The deliverables are divided based on the RIBA plan of work.
For *clash detection*, principles and strategies of clash detection must be defined first	Yes	The clash matrix and responsibility matrix have been set up to have principles for clash detection.
Cobie is not an important topic anymore and we do not need it to be in high detail in the Guide.	Yes	Cobie section is placed to generally explain the concept and the use of Cobie for the newbies.

At the end of the meeting, the second phase of validation consisting of a questionnaire to be distributed among all the BIMMS company staff, was discussed and approved.

3.3. Questionnaire Survey

For the second phase of validation, a questionnaire survey based on the developed BIM Guide was designed to gain validation and receive suggestions for the content of the BIM Guide from the experts working in the BIM area at BIMMS company. To this aim, an online questionnaire was developed using the "Cognito forms" platform (Figure 9). The survey link was sent to the BIMMS company collaborators and 20 of them participated in this research. The sample size of 20, included, 9 BIM Modelers/Specialists, 3 BIM Coordinators, 6 BIM Managers, and 2 Directors. The level of engagement of the respondents was extraordinary and it has been received multiple comments, suggestions, and validations for each question. For all questions, 95% of the respondents replied with a positive alignment with this proposal and this adds credibility to the work from the professional point of view. In this section, each question is analysed and the application of received comments are discussed. The whole text of the comments and suggestions is presented in Appendix 3.

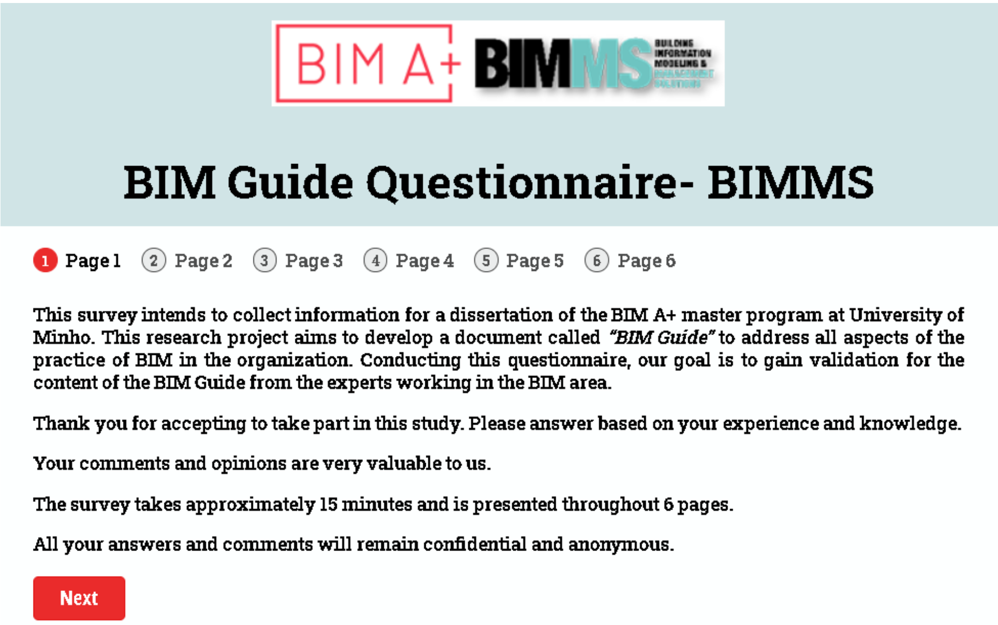


Figure 9 - The first page of the online questionnaire

The questionnaire and analysis

The questionnaire was developed in 8 questions with space for a justification on the chosen option for each question and a final request for optional commentaries. In this section, the questions are presented and immediately after each question, the responses analysis appears. The comments that were applied on the BIM Guide are coloured ***green*** and the ones that were not considered to the content of the BIM Guide are shown in ***pink***. There was a concern for keeping the process of answering the questions as simple as possible which came from the high volume of works of these professionals and their lack of time for the side tasks. For that, the limitation of time to 15 mins was one of the requirements and the other one was the choice for a simple scale of response. Instead of the simple scale of Yes, No and Neutral, it has been decided to have one No and on the Yes side, to divide it in 3 scales of Yes, namely “Absolutely Yes, Yes and Probably Yes”. By this method, the level of commitment and engagement of the respondents for each question could be measured.

Table 6 – The survey question 1

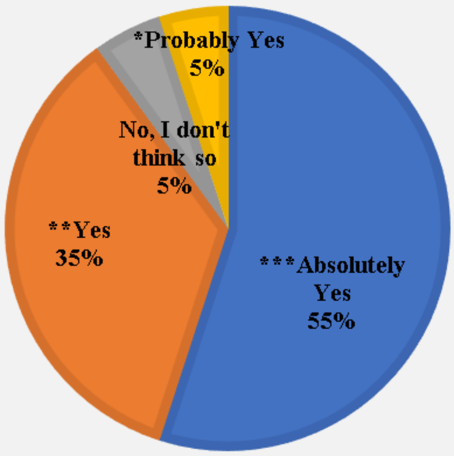
1. A BIM Guide is a living document that contains a set of procedures, guidelines and requirements for the practice of BIM in the organization. A few examples of published BIM Guides are Rail Baltica BIM Manual, Massport BIM Guidelines, Singapore BIM Guide, and Statsbygg BIM Manual. In your work, do you feel the need for a document like this to organize the way you do BIM?

O *Absolutely Yes*
O *Yes*
O *Probably Yes*
O *No, I don't think so*

If you wish, please indicate the reasons for your answer.

Table 7 - The survey question 1 analysis

Options	Responses	Percentage
***Absolutely Yes	11	55
**Yes	7	35
*Probably Yes	1	5
No, I don't think so	1	5
Total	20	100



The majority of respondents **-90%-** answered to this question by “**Absolutely Yes**” and “**Yes**” which shows there is a strong need for BIM guides in the organisation. Some of the reasons that they mentioned about the necessity of a guide can be summarised as:

- Provides a **good workflow** and **facilitates essential tasks;**
- **Standardises** organizational procedures;
- Gives a **better vision** of the whole BIM process;
- Provides formal **processes and standards** to follow;
- **Standardizes** workflows and guarantees quality;
- Provides **guidelines** on how to implement BIM.

Table 8 – The survey question 2

2. For the content of the BIM Guide that is being developed under this study, we came up with 4 main sections of Policy- People- Process- Technology and a few sub-sections. Each of the sub-sections contains a few topics as shown in the picture below. Do you consider this division logical and relatable to the BIM practice in your work?

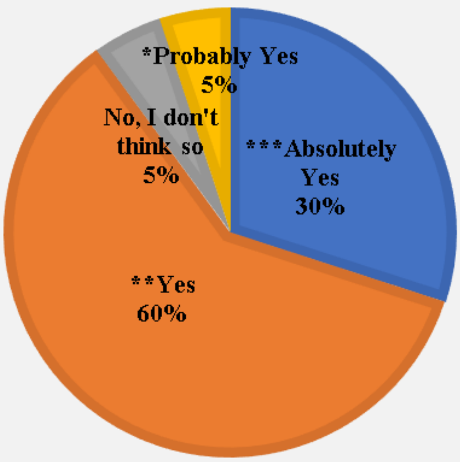
O *Absolutely Yes*
O *Yes*
O *Probably Yes*
O *No, I don't think so*

1. Policy		2. People	3. Process							4. Technology						
1.1. Regulatory	1.2. Contractual	2.1. Human resources	3.1. Product and services				3.2. Communication			4.1. Technical Standards			4.2. Software			
1.1.1. Standards and Classifications	1.2.1. BEP	2.1.1. BIM Roles & Responsibilities	3.1.1. BIM Uses	3.1.2. Deliverables	3.1.3. Lox	3.1.4. Quality Control	3.2.1. Collaboration Procedures	3.2.2. Clash Detection	3.2.3. COBie	4.1.1. Folder Structure	4.1.2. Naming Convention	4.1.3. Presentation Styles	4.2.1. Software and File Format	4.2.2. Software Template	4.2.3. BIM Object	4.2.4. Modelling Procedure

Would you suggest any modifications to this categorization? Is there any topic you consider missing? Is there any topic you consider useless?

Table 9 - The survey question 2 analysis

Options	Respondents	Percentage
***Absolutely Yes	6	30
**Yes	12	60
*Probably Yes	1	5
No, I don't think so	1	5
Total	20	100



Overall view of the topics in the BIM Guide proposal received a very high rate of validation, in **a way that 90%** of the respondents answered to this question by "**Absolutely Yes**" and "**Yes**". Also, they made several suggestions for the improvement and completion of the topics that you can see the summary below.

Comment	If applied	The changes applied/ Reasons for not applying the comment
Add "Volume Strategy" topic	Yes	The sub-topic of "federation strategy" is added to the technology cluster based on the terminology of ISO 19650.
Segregation strategy	Yes	The sub-topic of "federation strategy" is added to the technology cluster based on the terminology of ISO 19650.
Model Exchanges & Data Drops Protocols	Yes	The topic "data drops" is added under "information exchange and communication".
Review Procedures	Yes	The topic "review procedures" is added under "information exchange and communication".
Continuously being upgraded	Yes	It is a living document subjected to review and update regularly.
Modelling Procedures should be changed to section Process	No	The placement of the topics under the 4 clusters has been a difficult process with lots of studying and trying different methods. There is no consensus for this categorisation and this arguments weren´t considered enough to change the initial basis.
Chane the "Product and Services" under "Process" to "Execution Strategy"	No	The suggested name can be misleading as there are topics under technology cluster that are related to execution. The current naming is based on the research and scientific papers.
"Cobie" could stay as optional	No	It is considered essential to have it in the BIM Guide to explain the concept of it for the newbies.

Table 10 - The survey question 3

3. The table below shows various BIM Uses by project phases. Do you consider these BIM Uses practical and well-organized to be in the BIM Guide?

O *Absolutely Yes*
O *Yes*
O *Probably Yes*
O *No, I don't think so*

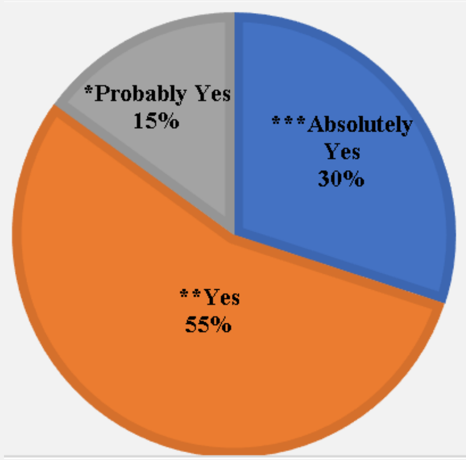
If you wish, please indicate the reasons for your answer.

Would you suggest any modifications to the table? Are there any BIM Uses that you consider missing in the table? Are there any BIM Uses in the table that you consider useless? (You may write the numbers associated with each use)

	BIM Uses	Plan	Design	Construct	Operate
1	Site Analysis				
2	Existing Conditions Modelling				
3	Design Authoring				
4	Design Options				
5	Phase and 4D Planning				
6	Energy Analysis				
7	Structural Analysis				
8	Lighting and Sun Analysis				
9	Engineering Analysis				
10	Sustainability Analysis				
11	Coordination/ Clash Detection				
12	Codes and Standards Compliance				
13	Design Review				
14	Create Construction Documentation				
15	Site Logistics Planning				
16	Temporary Construction Systems Design				
17	Fabrication				
18	Layout Construction Work				
19	Record Modeling				
20	Monitor Maintenance				
21	Asset Management				
22	Space Management				
23	Monitor System Performance:				
24	Quantity take-off and Cost Estimating				
25	Safety				
26	Disaster Planning and Management				

Table 11 - The survey question 3 analysis

Options	Respondents	Percentage
***Absolutely Yes	6	30
**Yes	11	55
*Probably Yes	3	15
No, I don't think so	0	0
Total	20	100



The BIM Uses proposal received a **very high rate of validation as all the answers include Yes and none of the respondents disagreed with the table of uses. 85%** of the respondents answered to this question by "**Absolutely Yes**" and "**Yes**". Also, they suggested several BIM Uses that are added to the table and they proposed some modifications in the phases that some uses appear in.

Comment	If applied	The changes applied/ Reasons for not applying the comment
Add BIM Supply Chain and Contract Management	Yes	The use of Contract Management is added to the provided uses.
Add Analytics, BIM to Field	Yes	The suggested uses are added to the list of uses.
Add Snagging, Augmented Reality	Yes	The suggested uses are added to the list of uses.
Engineering Analysis should be on the Plan phase	No	It starts from design phase, all the studied resources acknowledge this.
Space Management an asset management should be also in plan, design, and construction phases.	No	Based on the definition provided for these uses, their actual application is in the operation phase.
Add equipment management	No	It is synonymous to the existing use of asset management.
Add As-Built info	No	As-built info itself is not a use and it is utilised to prepare record model.

Table 12 - The survey question 4

4. Some of the deliverables for the BIM process divided by stages are listed in the table below. Are there any deliverables that you consider missing in this table? Are any deliverable in the table that you consider not applicable to the BIM process? (You may write the numbers associated with each deliverable).

	Deliverables	Stages
1	BEP	0- Strategic Definition
2	Existing Condition Model	1- Preparation and Briefing
3	Site Analysis	
4	Massing Model	2- Concept Design
5	Zoning	3- Spatial Coordination
6	Orientation	
7	Detailed Design Models	4- Technical Design
8	Shop Drawings	
9	Sustainability Analysis	
10	Detailed Energy Analysis	
11	System Cost Estimates	
12	3D Coordination Reporting	
13	Program Validation	
14	COBie Data	
15	Final Models	5- Manufacturing and Construction
16	3D Coordination Validation	
17	Cost Estimation	
18	Sustainability Reporting	
19	Construction System Design	
20	Phase Planning	
21	COBie Data	
22	Digital Fabrication	
23	Record Models	6- Handover
24	COBie Data	
25	Operation and Maintenance Manual	7- Use
26	Final as-built models fit for space management, building maintenance and modifications made during occupancy	

Table 13 - The survey question 4 analysis

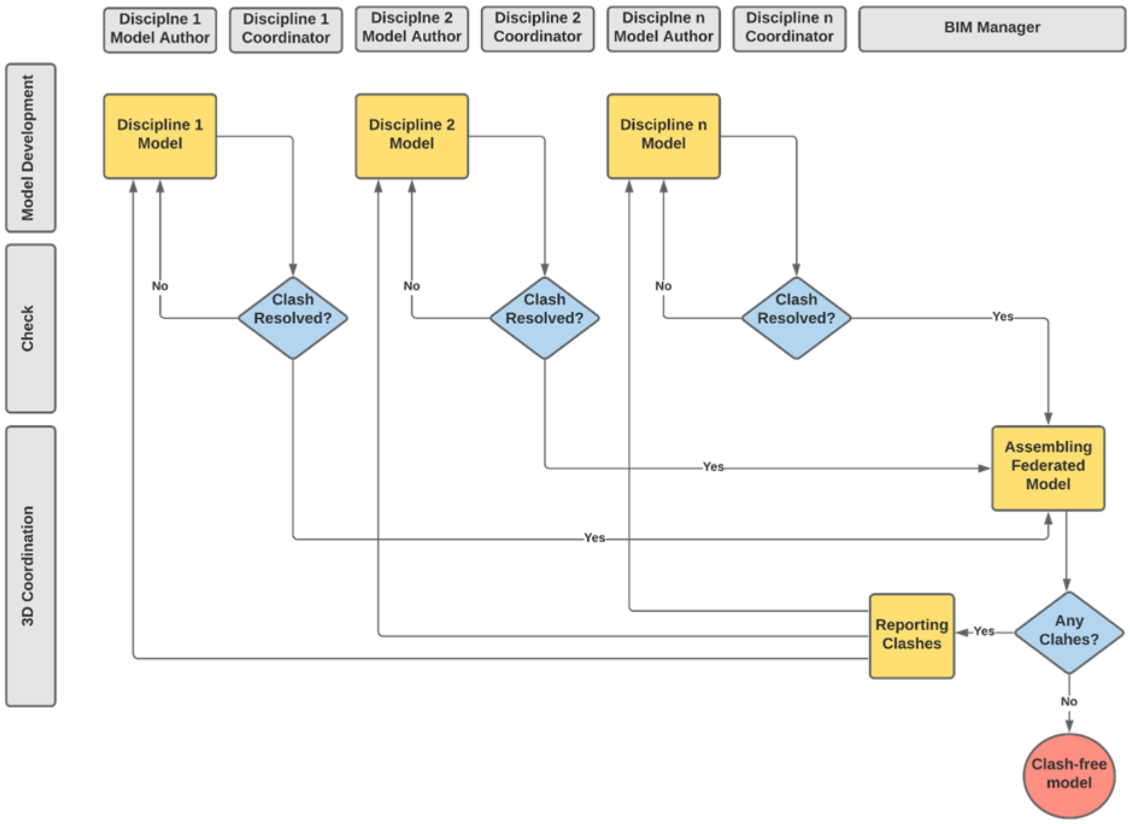
Survey respondents made **several positive comments** and also suggestions about the missing deliverables or the phases for delivering them that you can find the summary below.

Comment	If applied	The changes applied/ Reasons for not applying the comment
"Cobie" is only required when stated in BEP.	Yes	The deliverables are defined at the beginning of each project and documented in the BEP.
Review the standard deliverables of the RIBA plan of works	Yes	The table is completed based on the RIBA plan of work deliverables.
Spatial Coordination (Should Include: Drawings / 3D Coordination Reporting / Energy Analysis / QTO)	Yes	All the mentioned deliverables are added to the table.
Place shop drawings at the end of the technical design stage	Yes	The shop drawing place is changed
Change the name "final models" to "construction models	Yes	As there are also record model after the final model, so it is not the final model and the name changed to construction model.
3D scanning - point clouds	No	The point clouds and 3D scanning are used to prepare the existing condition model and record model and they are not themselves, generally, deliverables to the client.
There is repetition in terms of deliverables from stage to stage	No	This repetition is due to necessity of delivering that deliverable at different stages. It is the same deliverable with different level of development in each stage.
COBie Data is not necessary because IFC should resolve it	No	It will happen in the following years, but IFC has not taken over the Cobie yet. It is needed to have some protocols about information exchange during operation.

Table 14 - The survey question 5

5. For clash detection, do you consider this workflow an appropriate clash detection process?

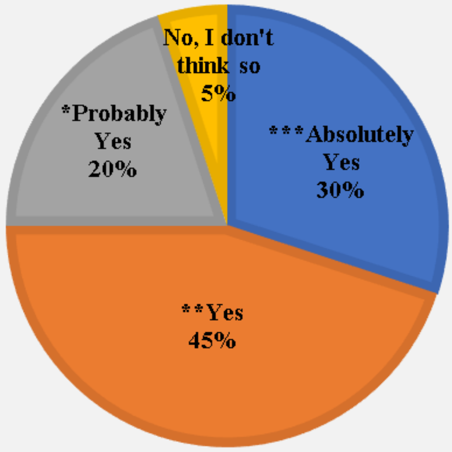
O *Absolutely Yes*
O *Yes*
O *Probably Yes*
O *No, I don't think so*



Would you suggest any changes to the workflow to make it a practical clash detection process?

Table 15 - The survey question 5 analysis

Options	Respondents	Percentage
***Absolutely Yes	6	30
**Yes	9	45
*Probably Yes	4	20
No, I don't think so	1	5
Total	20	100



The majority of the respondents **-75%-** answered to this question by "**Absolutely Yes" and "Yes**". Which is pretty good validation rate and 20% responded by "Probably Yes". One of the respondents did not agree with the workflow and commented about how to improve it which is applied to the workflow along with other applicable comments.

Comment	If applied	The changes applied/ Reasons for not applying the comment
Construction tolerances should be established	Yes	Considering the tolerances is added to the workflow.
Feed the workflow with priority matrix	Yes	The priority matrix is part of the clash detection process, and it is added to the workflow.
Clash detection activity shall be performed by the BIM Coordinator instead of BIM Manager.	Yes	The responsibilities are documented in the BEP, and it can differ in each project. The BIM manager is changed to BIM coordinator to suit the general workflow of BIMMS.
Project coordinator can prioritize disciplines	Yes	BIM coordinator decides which discipline is responsible based on priority matrix.
Flip the workflow to make the BIM manager role the first	No	A phase for inter-discipline check is existed before the 3D coordination that is done by discipline coordinator so cannot be flipped.

Table 16 -The survey question 6

6.There are some types of Quality Control that are implemented during the projects. Do you consider the 4 types of checks shown in table below necessary?

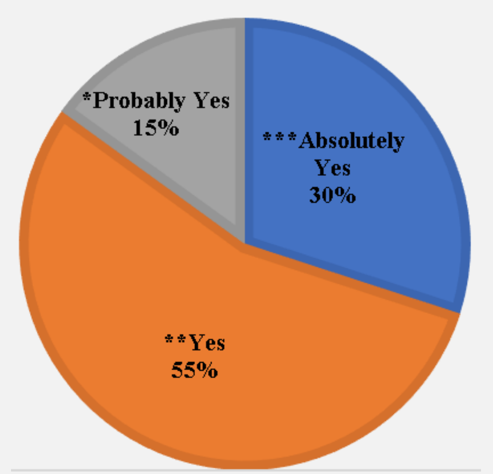
O *Absolutely Yes*
O *Yes*
O *Probably Yes*
O *No, I don't think so*

TYPE OF CHECK	INSTANCES
Visual Check	Model coordinate and orientation No unnecessary component in the model The compliance with defined LOD Coordination between Native and IFC files Ensure design intent has been followed Model files are up-to-date, containing all users' local modifications Model files are detached from central file All floor levels defined and uniquely named All Drawings and Exported Sheets are extracted from the model The building sections are completely dimensioned and annotated
Clash check	Interferences between elements.
Data Check	Crosschecking between client's data and data inserted in the software File format, naming conventions and folder structure Using the standard project template
Standards Check	The compliance of the design against the technical design guidelines for each discipline and established classification for example Uniclass 2015

Would you suggest any changes that might make more sense to your particular experience? Are there any other quality checks that you consider missing in the table? Are there any other quality checks that you consider useless in the table? (type or instance)

Table 17 - The survey question 6 analysis

Options	Respondents	Percentage
***Absolutely Yes	6	30
**Yes	11	55
*Probably Yes	3	15
No, I don't think so	0	0
Total	20	100



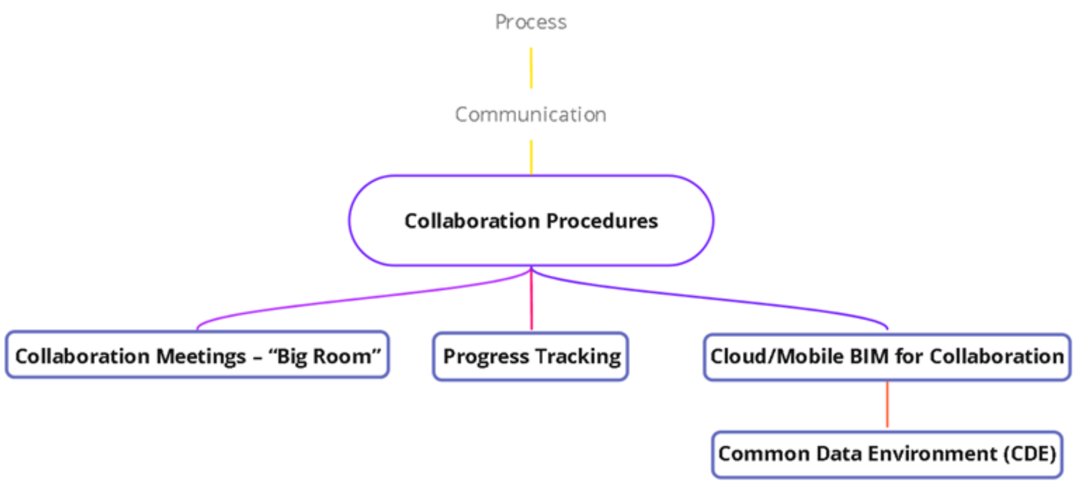
85% of the respondents answered to this question by "**Absolutely Yes" and "Yes**". Which is high validation rate and 15% responded by "Probably Yes" and there is no negative response. This shows the quality check proposal is mostly complete and applicable.

Comment	If applied	The changes applied/ Reasons for not applying the comment
Schedule layout	Yes	It is part of the compliance with template check.
I don't think that every drawing or schedule should necessary be extracted from the model.	Yes	It is correct, there is still drawings that are not extracted from the model.
Overall health of the model	Yes	The checks altogether will ensure the overall health.
Search of the project missing items	No	Crosschecking of the data is considered the same.
The process of quantity extraction	No	The process is a different subject from the quality check and is not applicable here.
Optimisation process	No	The optimisation process is a different subject from the quality check and is not applicable here.

Table 18 – The survey question 7

7.For the team to collaboratively produce and manage information, some Collaboration Procedures are defined that are illustrated in the picture below. Do you consider these procedures helpful in having effective collaboration?

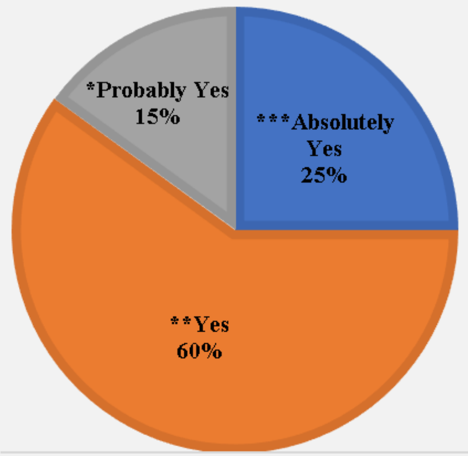
O *Absolutely Yes*
O *Yes*
O *Probably Yes*
O *No, I don't think so*



Would you suggest any changes? Is there anything that you would you add or remove to have successful collaboration throughout the project?

Table 19 - The survey question 7 analysis

Options	Respondents	Percentage
***Absolutely Yes	5	25
**Yes	12	60
*Probably Yes	3	15
No, I don't think so	0	0
Total	20	100



Overall, 85% of the respondents answered to this question by "**Absolutely Yes**" and "**Yes**". Which is high validation rate and 15% responded by "Probably Yes" and there is no negative response. There are a few comments received that are applied to improve the collaboration procedure section.

Comment	If applied	The changes applied/ Reasons for not applying the comment
The purpose could be associated to each of the 3 elements	Yes	The elements are modified to add more relevance and purpose to them.
How to use collaborative data to provide trustful information about productivity, progress evaluation and quality control	Yes	The topics such as review process added to is added to collaboration procedure that encompass the suggested points.

Table 20 – The survey question 8

8.Do you consider it useful to have software templates in the practice of BIM?

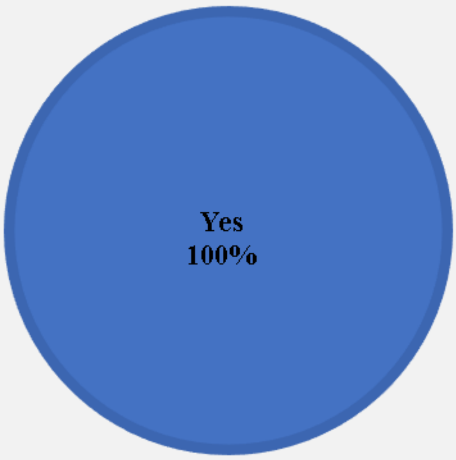
- O *Yes*
- O *No*

The table below presents some templates that might be useful. Would you suggest any other templates that you consider useful to be included in the BIM Guide?

	Template
1	Project Browser Organization
2	Project Information
3	Units
4	Starting View
5	Schedules
6	Object Library
7	Text and dimensions
8	Line styles
9	Line weights
10	Line patterns
11	Annotation symbols
12	Fill patterns
13	Materials
14	Title blocks
15	sheets
16	Views
17	View Templates
18	Phases

Table 21 - The survey question 8 analysis

Options	Respondents	Percentage
Yes	20	100
No	0	0
Total	20	100

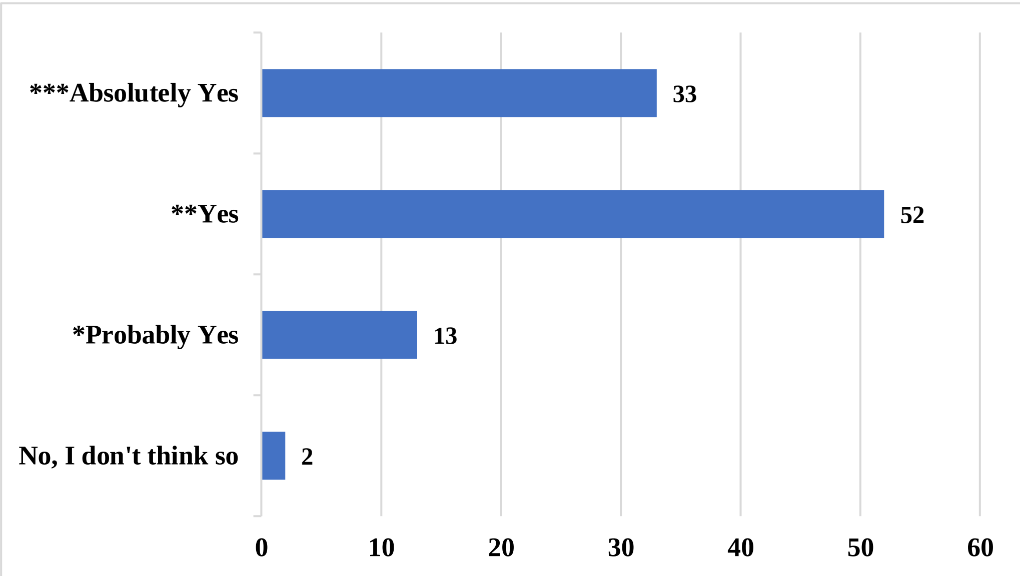


All of the respondents believe that the software template is essential in the BIM process, and they suggested a few of other templates that are not provided in the table to be included in the Guide**.**

Comment	If applied	The changes applied/ Reasons for not applying the comment
Plot styles settings	Yes	Line style, pattern, weight, are related to plot setting.
Shared Parameters.	Yes	It is added to the template section.
Family Content Convention	Yes	The content library and family template are added to the templates.
Families Template	Yes	It is added to the template section.

As a final remark, Table 22 presents an overview of the answers to the questionnaire altogether. As it is shown, only 2% of all the responses is disapproval and 98% of the responses are different degrees of Yes. Majority of the responses are **Yes** with the percentage of 52 and **Absolutely Yes** with the percentage of 33 which means, in total, 85% of the responses validate the content of the BIM Guide in a high degree.

Table 22 – Overview of all responses to the questionnaire in percentage



3.4. Introduction to the BIM Guide Proposal

To organise the final classification, a model of four knowledge clusters of BIM Guide and the elements for each cluster is demonstrated in Figure 10. These elements are the primary proposed elements along with new suggested elements.

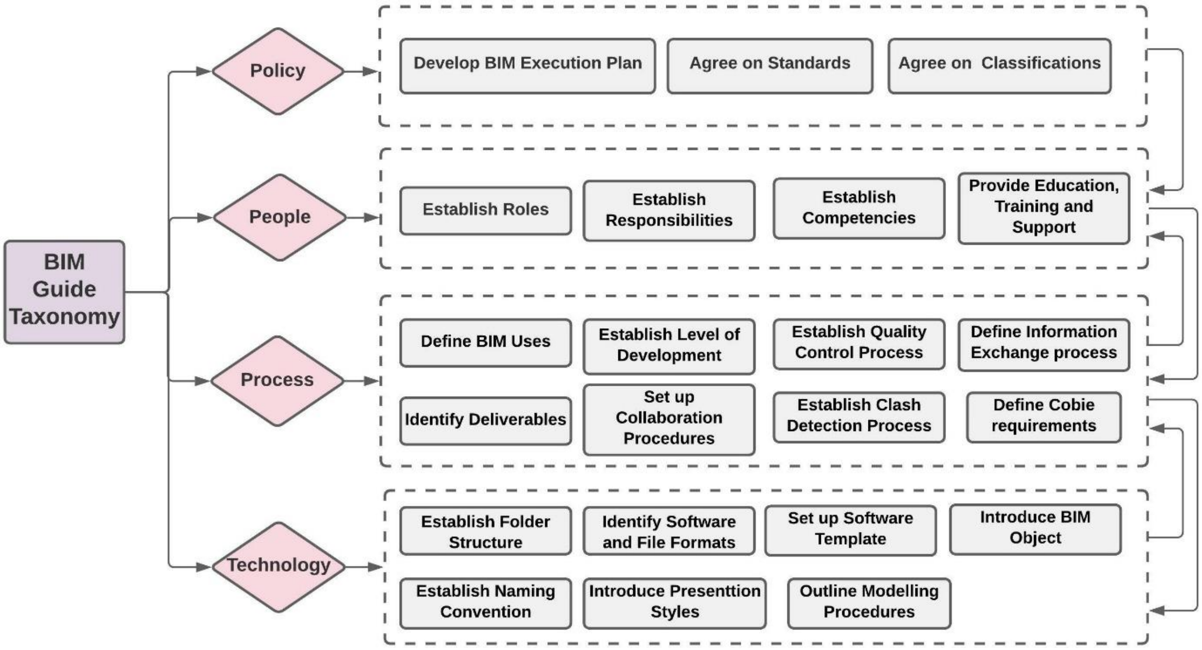


Figure 10 - The knowledge clusters and the required elements

Below (Figure 11) is the mind map of BIM Guide proposal content. This mind map illustrates the final classification of the topics after applying the modifications based on the results of the two phases of validation- BIMMS meeting and questionnaire survey. This framework is intended to organize domain knowledge and facilitate its understanding.

It is worth noting that there is no single correct solution for the BIM guide structure and the proposed framework is one of the alternatives that resulted from the extensive study of existing BIM guidance documents and papers as well as BIM professionals' opinions.

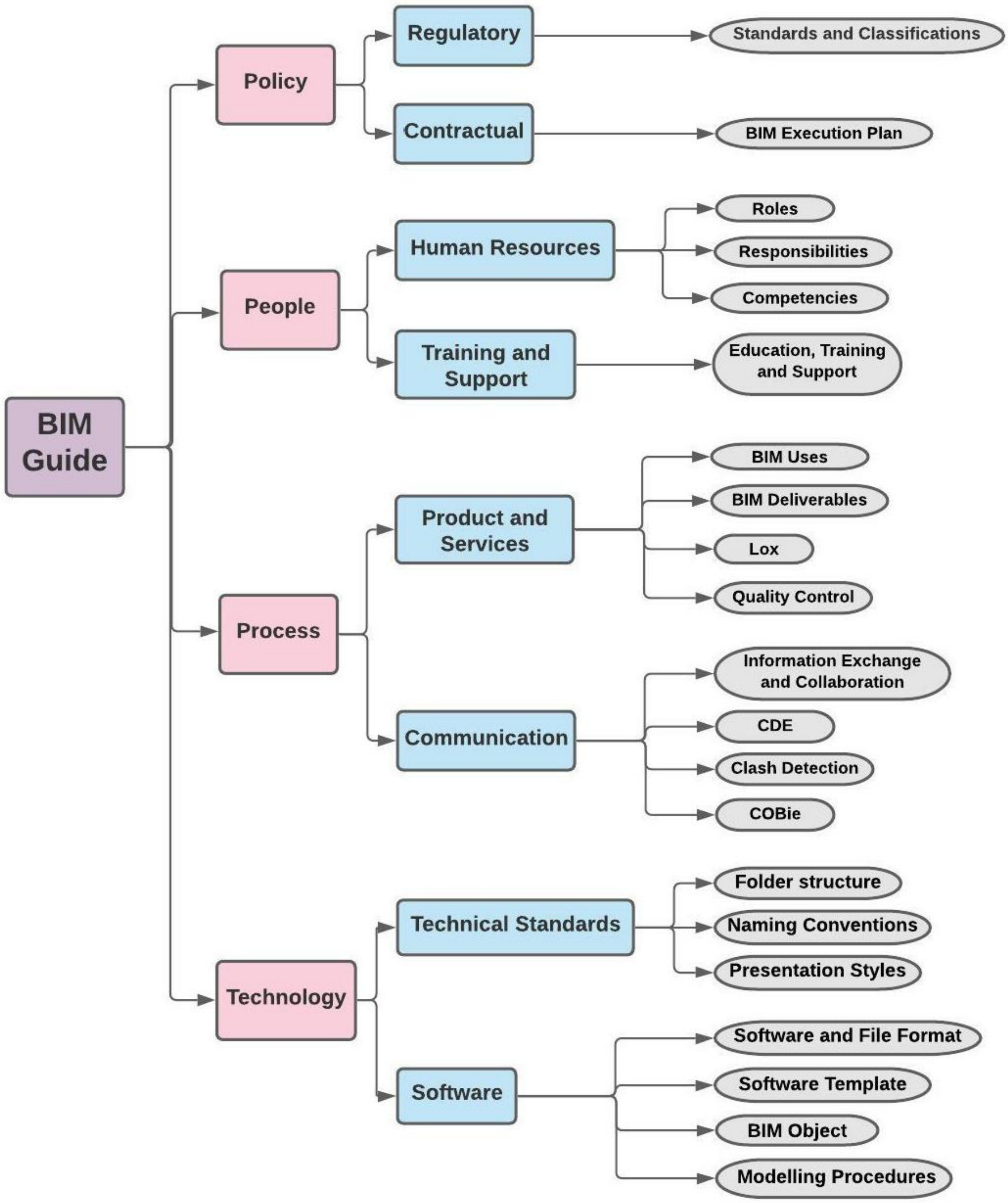


Figure 11 – BIM Guide proposal mind map

BIMMS BIM Guide will use terminology and references that are unique to the Autodesk suite, specifically Autodesk Revit as the BIM authoring tool.

In case of conflicts between the BIM Guide recommendations and the Project BEP, the BEP takes precedence. For example, if any other software except for Revit is defined in the BEP as the authoring tool, the BEP requirements must be followed.

BIMMS BIM Guide that is presented in four chapters and next chapter “Policy” is the initial chapter of it. This guide aims to provide construction players with policy, strategic and implementation level recommendations for the introduction of BIM the organisation.

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4. POLICY[1i]

Policy is "*a high-level overall plan embracing the general goals and acceptable procedures*" (Merriam-Webster, 2021) and also policies can be defined as "*written principles or rules to guide decision-making*" (Succar, 2009). This section covers the **Policy** knowledge cluster that contains **Regulatory** and **Contractual** sub-sections.

4.1. Regulatory

Deciding what standards and classification systems to follow depend on many factors such as the country which the project is located, the organisation internal standards, and the project itself.

4.1.1. Standards

Building information modelling (BIM) standards supports the adoption and implementation of BIM. These standards define the minimum requirements and give further recommendations on applying the best practices. There are a few types of standards: A. International B. National or Regional C. Organizational and D. Project-, or Facility-, specific.

However, the international BIM standards offer the potential to act as a passport for organizations that embed them to gain access to international markets (UK BIM Alliance, 2019). The standards considered on this BIM Guide are:

- ISO 19650 series
- ISO 16739-1:2018

ISO 19650 series

The ISO 19650 standard is an international standard for managing information over the whole life cycle of a built asset using BIM. In January 2019, the final version of ISO 19650-1 and - 2 were published. In UK it supersedes the BS 1192:2007+A2:2016 and the Publicly Available Specification (PAS) 1192-2:2013.

The ISO 19650 has two parts related to information management which are:

ISO 19650-1: Organization and digitization of information about buildings and civil engineering works, including building information modelling -- Information management using building information modelling: Concepts and principles.

ISO 19650-2: Organization and digitization of information about buildings and civil engineering works, including building information modelling -- Information management using building information modelling: Delivery phase of the assets.

[1] BIM Guide proposal comprises four main knowledge clusters that are presented in four chapters throughout the dissertation. "Policy" is the first chapter of the BIM Guide proposal. For more information on the structure of BIM Guide refer to 3.4 Introduction to the BIM Guide Proposal.

The ISO 19650 series describes and defines information management across the whole life cycle of an asset. To support this there need to be close links with the approaches taken to asset and project management, and to organizational management. This can include adoption of the appropriate ISO management system standards (see Figure 12) but this is not a prerequisite to implementing the ISO 19650 series (UK BIM Alliance, 2019).

The ISO Standard defines Information Management requirements for the process management as illustrated in Figure 12. In this management system, Delivery phase utilizes the Project Information Model (PIM), and an Operational phase uses the Asset Information Model (AIM). Between the two phases, information is collected, processed, approved, used, and finally stored.

Figure 12 - Information Management process according to ISO Standard (BSI, 2019a)

The ISO 19650 series refers to the appointing party, lead appointed party and appointed party and also to the project team, delivery team and task team.

The parties and relationships in simple terms are as follows:

- The appointing party is the client or the party managing information on behalf of the client.
- A lead appointed party is a party appointed by the client.
- An appointed party is a party appointed by the lead appointed party. The appointed party is the party that provides the information. See Figure 13.

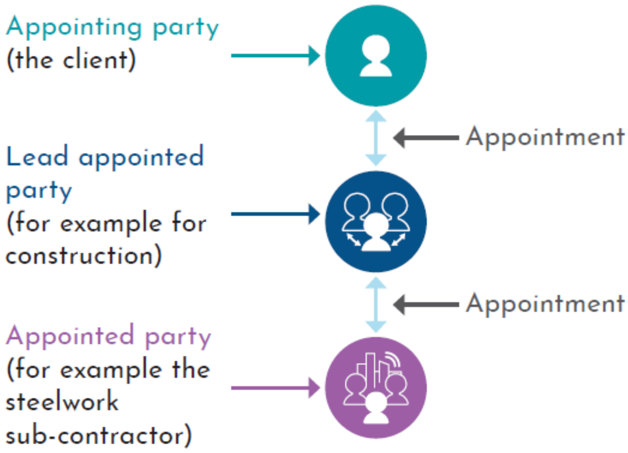

Figure 13 - Simple party/appointment relationship (UK BIM Framework, 2021a)

ISO 16739-1:2018

This standard presents Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries — Part 1: Data schema

The Industry Foundation Classes, IFC, are "*an open international standard for Building Information Model (BIM) data that are exchanged and shared among software applications used by the various participants in the construction or facility management industry sector. The standard includes definitions that cover data required for buildings over their life cycle*" (ISO 16739–1, 2018).

IFC is the base format for BIM models in any project that are demanded to comply with OpenBIM approach.

4.1.2. Classification Systems

In construction projects, huge amounts of complex information need to be filed, retrieved, and referred to. Classification Systems allows us to order this information in a controlled and consistent manner, to provide a common understanding between specialities. A classification system may be built on a well-organized framework that can be more granular when it is broken down into smaller subsets. For example, the NBS describe a classification system as "*a hierarchical suite of tables that support classification of all "things" from a university campus or road network to a floor tile or a kerb unit*" (UK BIM Alliance, 2019). By assigning the proper classification code to product models, they can be utilised for construction information or cost estimation. There are various classification systems developed by different countries and institutions such as DBK in Denmark, OmniClass or MasterFormat in North America, and Uniclass in the UK, each of them has its own way of classifying the construction artifacts (Afsari and Eastman, 2016). The choice of classification system depends on various factors that can the project location, previous firm experience, and project requirements (Zaker Hosein, 2019).

The classification system currently referred in this BIM Guide is Uniclass 2015.

Uniclass 2015

Uniclass is a consistent classification structure for all disciplines in the construction industry. It includes tables that categorises items of any scale from a large facility such as a railway, down to products such as a CCTV camera in a railway station. It is an essential way of identifying and managing the vast amount of information that is involved in a project, and it is a requirement for BIM projects, as set by the ISO 19650 series of standards (NBS, 2019).

Uniclass 2015 has been carefully structured to be in accordance with ISO 12006-2 Building construction – Organization of information about construction works – Part 2: Framework for classification. This means that Uniclass 2015 will be particularly suited to use in an international context where mapping to other similarly compliant schemes around the world should be streamlined. Uniclass 2015 is divided into a series of tables that can be used to organise data for costing, briefing, CAD layering, and other purposes, as well as for generating specifications or other production documents (Delany, 2019).

4.2. Contractual

The Contractual terms that will rule the relations for the requirement, development, and delivery of BIM in a project are of upmost importance. It will define the relations between all actors, their roles and responsibilities, the deliverables as well as the digital formats, and storage and transmission platforms that will apply.

The contractual type of relation (Design-Build; Design-Bid-Build; IPD-Integrated Project Delivery, among others) will conditionate what BIM could be delivered.

Several documents could specify these contractual relations. On this Guide it will be referred the EIR (Exchange Information Requirements) and the BEP (BIM Execution Plan).

4.2.1. EIR – Exchange Information Requirements[2]

The client/appointing party should always clarify what are their expectations on the BIM process. Those expectations should be delivered on a form of document called EIR – Exchange Information Requirements that should include the managerial, commercial, and technical aspects of developing the project information. These requirements will constitute the basis for the BIM contract and will be the main source to solve conflicts between parties.

4.2.2. BEP - BIM Execution Plan

The BIM Execution Plan (BEP) is a document that describes how the BIM project will be implemented, monitored, and organized. BEP must be prepared for every project as a direct response to the Exchange Information Requirements and Technical Specifications (EIR/TS).

The intent of the BEP is to provide a framework that will ensure effective collaboration of all parties involved at all stages of BIM project. It defines goals, objectives and people's roles and responsibilities.

[2] The EIR is not one the main topics that included in the BIM Guide proposal from the outset since it is not a topic covered in this kind of BIM guidance document. However, there is a need to have a clarification on the concept as the term will be mentioned in the Guide in several parts.

It also outlines how the process will be carried out through the project's life cycle as well as the technological infrastructure required for the project.

Based on the Messner et al. (2021) a five-step procedure should be followed to develop detailed, consistent plans for projects. The five steps, shown in Figure 14, consist of identifying the appropriate BIM goals and uses on a project, designing the BIM execution process, defining the BIM deliverables, and identifying the supporting infrastructure to execute the plan successfully.

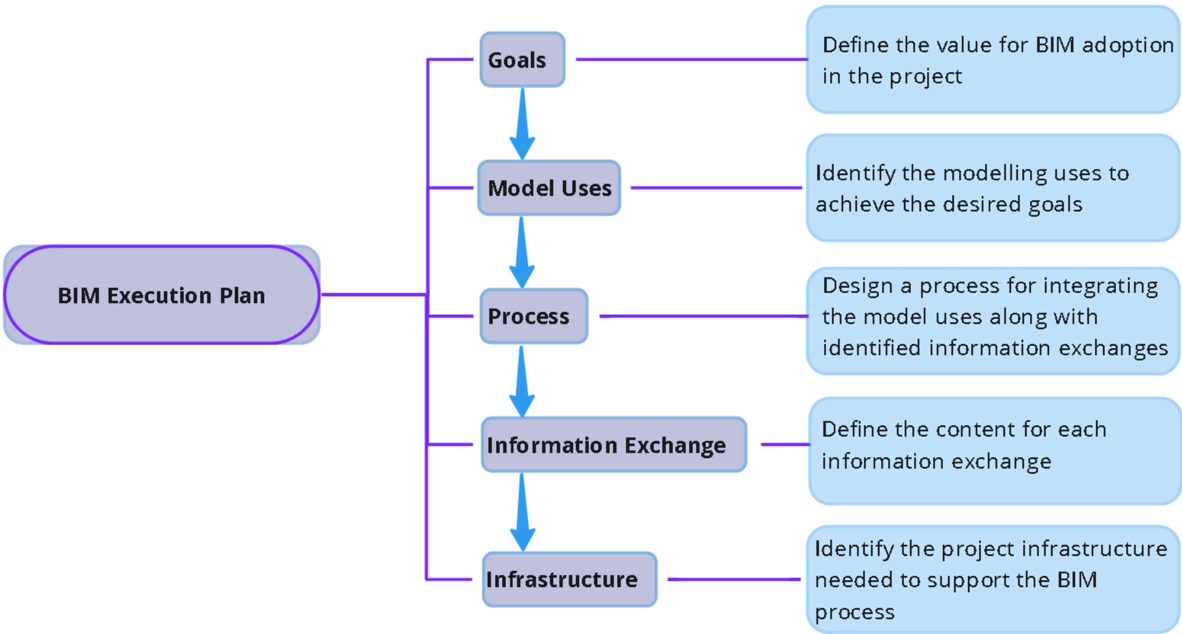

Figure 14 - The BIM Project Execution Planning procedure. Adapted from (Messner et al, 2021)

For an effective BIM project, the BEP should be developed by the most experienced, certified, and qualified individual on the team before the initial stages of a project.

However, it is considered a dynamic and living document, in a sense that it can be updated throughout the project's life cycle. Some of the situations that may require a revision on the BEP include:

- Changes in processes
- Changes in BIM requirements
- Changes in team members or stakeholders
- Changes in BIM Schedule (Coordination sign-off dates, LOD milestones, etc.)

In general, the responsible party shall submit the initial version of the project BEP within 30 days of receiving the Notice to Proceed on the project.

The categories of information that a BEP should generally address are:

Project Overview – This section should contain essential project information such as project numbers, project location, project description, key Project Contacts, and critical schedule dates for future reference.

Project Goals/ BIM Uses - This topic should include the strategic value and specific BIM uses on the project as defined in the initial stage of the planning procedure.

Roles and responsibilities - This section should specify the coordinators of the project execution process as well as the required personnel and their responsibilities to successfully implement the project.

BIM Process Design - This topic should contain the project process maps to show the project execution process.

BIM and Facility Data Requirements - This section should address the owner's requirements for BIM

Information Management & Exchange - In the information exchanges requirements, the model elements and level of detail required to implement each BIM Use should be clearly determined.

Collaboration Procedures - The project team members should define model management procedures such as file structures and file permissions. Meeting schedules and agendas should clearly be determined.

Quality Control - This section should include a framework to ensure that the project deliverables meet the defined requirements and standards throughout the project.

Technological & Infrastructure Needs - This section should define the hardware, software and network infrastructure required to execute the project.

Modelling Standards and Model Structure - Model structure, file naming structure, coordinate system, and modelling standards should be agreed and documented by the project team members.

Project Deliverables - The deliverables required by the appointing party is documented in the BEP.

Delivery Strategy/ Contract - This section should define the project delivery strategy namely design-build, design-bid-build, and integrated project delivery. The delivery strategy will impact implementation and the language which should be incorporated into the contracts (Messner et al, 2021).

BIM Execution Plan is a project plan which is defined for each project specifically based on the project's goals and characteristics and The BIM Guide is an organizational guidance document. Therefore, in case of conflicts between the BEP and The BIM Guide, the BEP has the priority.

5. PEOPLE[3]

This section covers **People**[4] knowledge cluster that contains **Human Resources** and **Training and Support** sub-sections.

5.1. Human Resources

This section describes the BIM roles, responsibilities, and expected competencies of the team members involved in the BIM Projects of the organization. These roles and responsibilities may vary depending on the Project Delivery Model and specific project conditions.

5.1.1. BIM Functions (Roles) [5]

Studies have shown the international emergence of three main roles or functions based on ISO 19650 as BIM manager, BIM coordinator, and BIM modeler. There has been some research on the forming of BIM related roles, their tasks, and how BIM actors are perceived by other actors in the industry[6].

BIM Manager – project or organizational role

As BIM Dictionary (2019) defines, BIM Manager is "*A person responsible for leading the BIM Implementation process within an organization and supporting it in developing/delivering new BIM services and model-based efficiencies*". The BIM manager develops and maintains BIM procedures and protocols including BEP, EIR, scope, and strategies.

BIM Coordinator

A person who acts as an intermediary between the BIM Manager and the modelling team. He/she implements the BIM Manager's modelling standards and protocols and deals with the day-to-day coordination of team members to achieve project goals (NASPEC, 2016). The BIM Coordinator maintains and controls a single discipline team model, whereas the BIM Manager is in charge of the final Federated model. In a study by Jacobsson& Merschbrock (2018), 183 documents including articles, theses, conference proceedings, and books were found in a search for BIM coordinator term. The aggregated review result demonstrated the responsibilities of a BIM coordinator. See Table 23.

BIM Modeler

It is the position to develop the model, produce the design documentation and quality check.

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[3] The current BIM Guide proposal comprises four main knowledge clusters that are presented in four chapters throughout the dissertation. "People" is the second chapter of the BIM Guide proposal. For more information on the structure of BIM Guide refer to 3.4 Introduction to the BIM Guide Proposal.

[4] According to a study by Won et al. (2013), the most challenging issue in adopting BIM is "people" related issues. Nine out of ten critical success factors for BIM projects were related to people and procedural issues rather than technical issues.

[5] BIM roles topic appeared in the 12 out of 19 reviewed BIM guides for this study. As illustrated in Appendix 4, the three main roles of BIM Manager, BIM Coordinator, and BIM Modeler are the roles that are defined in most of these guides.

[6] As Barison and Santos (2010) identified from the technical literature, and later found in an analysis of BIM job advertisements (Barison and Santos, 2011), there is a vast diversity of job titles which apply to BIM specialists. Uhm et al (2017) identified 35 job types through a study of job postings, many of which had overlapping descriptions and requirements. The research shows how the definition of BIM specialists is ambiguous and suggests the necessity of a clearness for BIM roles in organization and project terminology (Davies et al., 2017).

5.1.1. Roles and Responsibilities

The responsibilities of the three main BIM specialist roles can be classified into three primary functions in BIM process: Strategic, Tactical and Operational.

Strategic – BIM Management

This role represents the company's BIM Manager, who is responsible for defining and making strategic decisions about BIM implementation and support training.

Tactical – Coordination

This role represents is held by the BIM Coordinator whose responsibilities are mentioned in the matrix below.

Operational – Modelling/Authoring

The architects, engineers, designers, and BIM modelers who produce information for the BIM model are represented by this role.

The responsibilities of each role divided by three BIM functions are illustrated in the matrix below.

Table 23 - Roles and responsibilities. Adapted from (AEC(UK), 2015)

Responsibilities / Roles	Strategic						Tactical				Operational	
	Corporate Objectives	Research	Process + Workflow	Standards	Implementation	Training	Execution Plan	Model Audit	Model Co-ordination	Content Creation	Modelling	Drawings Production
BIM Manager	■	■	■	■	■	■	■					
BIM Coordinator						■	■	■	■	■	■	
BIM Modeler										■	■	■

It is important to note that these are not job titles, and that the same person can fulfil many roles and functions.

5.1.2. Competencies

Studies that focus on the BIM roles have discussed different forms of competency on the individual level (Uhm et al., 2017, Succar et al, 2013). There is no consensus among researchers on the exact definition of the term competency. Competency is a "combination of skills, abilities, and knowledge needed to perform a specific task" as defined by Jones & Voorhees (2002)[7].

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[7] Based on the definition of Berio& Harzallah (2005), a competency is a "way to put in practice some knowledge, know-how and attitudes, inside a specific context. Also, Succar et al (2013) defines competency as "an individual's ability to perform a specific task or deliver a measurable outcome".

Overall, competency is viewed in terms of (1) personal traits- attitude or behaviour; (2) knowledge – conceptual and theoretical; and (3) skill – procedural and applied knowledge (Succar, 2013). To define BIM specialists' role in the organization, measuring the individual's competency is the key to ensure that the actors possess required skill sets and capabilities for the role.

5.1.3. BIM Competency Matrix

Terrosi (2020) investigates the how traditional roles have changed after BIM adoption and explains BIM roles and traditional roles along with their responsibilities and required competencies. Some of the roles may overlap, for example, the leading architect also functions as BIM Manager and another experienced one also functions as BIM Coordinator. The company BIM Managers may utilize BIM Competencies Matrix (Table 24) to evaluate and choose the right person for each role.

Table 24 - BIM competency matrix. Adapted from (Terrosi, 2020)

Role	Role's Responsibility	Expected Role's Competencies
Appointing Party	- Write a proper EIR	-Scope of work -Strategy -Organization and Planning (set project deliverables, schedules) -Coordination -Open Collaboration (IPD) -Standardisation -LOD
Architect	- Design	-Technical skills - Software skills - Coordination (IPD) - Communication - Quality Control
Engineer	- Explore different solutions according to architectural design	- Technical skills - Software skills - Communication - Quality Control
Project Manager	- Ensure the entire team will achieve the appointing party's requests according to specifications	- Organization and Planning - Coordination (IPD) - Communication - Strategy
Contractor	- Identify design issue before the construction phase starts	- Technical skills - Software skills - Coordination (IPD) - Information Modelling
Quantity Surveyor	- Manage and control project costs and contractual administration	- Technical skills - Software skills - Modelling skills - Information Modelling
Facility Manager	- Responsible for the logistic and planning use asset	- Technical skills - Information Modelling - Coordination (IPD)
Information Manager	- Have an overview of the entire information requirements	- Coordination - Communication - Strategy

BIM Manager	- Develop a proper BEP, establish protocols, coordinate, and keep the different teams updated and take care of the federated model. - Control the overall model quality, design specifications and delivery specifications. - Assure the information produced by the teams are compliant with the BEP and the EIR.	- Scope of work - Strategy - Organization and Planning (set milestones and deliverables) - Coordination representing the teams' interdisciplinary models - Open Collaboration (IPD) - Standardisation - Management and quality control of the information model meets the requirements - Create standards and protocols - Create process and workflows - Training strategy - Research
BIM Coordinator	- Manage and control the single discipline model reviewing and approving the information produced.	- Organization and Planning (set milestones and deliverables inside the team) - Standardisation - Management and quality control of the information model - Create process and workflows for the disciplinary team
BIM Modeler	- Prepare 3D models and technical drawings; - Generate 4D and 5D models; - Modelling and synchronizing of data/ federation of models.	- Technical skills - Software skills - Modelling skills - Information Modelling
BIM Consultant	- Integrate, check, and coordinate the information received from all parties - Configure information for project output - Accept/reject information exchange within the CDE - Develop data structure for deliverables	- Support the company and the teams in the BIM use and adoption - Verification of the project team's competency level - Team's training - Implement strategies, protocols, and workflow - Knowledge exchange concerning tools, software and knowledge of BIM for the company - Creating best-practice documents - Teaching new working methods - Research

5.1.4. RACI matrix

Terrosi (2020) developed a RACI matrix for the roles and deliverables[8]. A RACI matrix is a form of responsibility assignment matrix, and it is an acronym of Responsible, Accountable, Consulted, and Informed. These designations can be given to individuals involved in a BIM process:

- Responsible: the person in charge of the process and there can only be one responsible person for that process. This person has the responsibility of producing what is required to be delivered.

[8] Refer to 6.1.2 for more information on deliverables.

- Accountable: the person the responsible person reports to and who must sign off on decisions and there can only be one accountable person for that process.
- Consulted: People who will be involved in discussions about the process.
- Informed: People who will need to be told about the process.

This matrix (Table 25) is used to assign and track stakeholders' responsibilities throughout the project. Regarding the deliverables, each role can have several tasks to accomplish. The matrix can be filled in once roles and tasks have been defined. The matrix in higher quality is presented in Appendix 5.

Table 25 - RACI matrix (Terrosi, 2020)

Role	Deliverable																								
	Concept Model	Architectural Model	Structural Model	MEP Model	Architectural Schedules Quantities Details Costs	Structural Schedules Quantities Details Costs	MEP Schedules Quantities Details Costs	Provide Specific Model Objects	Object's Library	Clash Detection Architectural Model	Quality Assurance Architectural Model	Clash Detection Structural Model	Quality Assurance Structural Model	Clash Detection MEP Model	Quality Assurance MEP Model	Clash Detection Federated Model	Quality Assurance Federated Model	Validation Federated Model	Clash Detection Federated Model for Submission	Quality Assurance Federated Model for Submission	Validation Federated Model for Submission	Clash Detection Federated Model for Construction	Quality Assurance Federated Model for Construction	Validation Federated Model for Submission	Shop Drawings
Client/Owner	C	I																I			I			I	
BIM Consultant										I	I	I	I	I	I	I	I		I	I		I	I	I	I
BIM Manager (Architect)	I	I	I	I	I	I	I		A	I	I	I	I	I	I	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A
BIM Coordinator Architects Task team		C			A				C	A/R	A/R					C	C	I	C	C	I	C	C	I	R
Architect Designer Team Leader	R	A	C	C						I	I					I	I		I	I		I	I		
BIM Modeller Architects Task team		R			R					C	C														
BIM Coordinator Structural Engineers Task team			C			A			C			A/R	A/R			C	C	I	C	C	I	C	C	I	R
Structural Engineer Team Leader		C	A	C								I	I			I	I		I	I		I	I		I
BIM Modeller Structural Engineers Task team			R			R						C	C												
BIM Coordinator MEP Engineers Task team				C			A		C					A/R	A/R	C	C	I	C	C	I	C	C	I	R
MEP Engineer Team Leader		C	C	A										I	I	I	I		I	I		I	I		I
BIM Modeller MEP Engineers Task team				R			R																		
Contractor Main																						C	C	I	R
Sub-Contractor																						C	C	I	R
Facility Manager		C	C	C																		C	C	I	R
Supplier 1								R	R																
Supplier 2								R	R																

R Responsible = Assigned to complete the task or deliverable.
A Accountable = Has final decision-making authority and accountability for completion. Only 1 per task.
C Consulted = An adviser, stakeholder, or subject matter expert who is consulted before a decision or action.
I Informed = Must be informed after a decision or action.
A/R Accountable and Responsible

5.2. Training and Support

Training[9], education, and support are the crucial factors in the successful practice of BIM in the organization. Adequate education and training of project team member will ensure that they have acquired necessary skills to successfully collaborate in the BIM projects. The lack of such training may cause resistance to change among the personnel of the organization.

To encourage their development, key BIM staff should undergo continuous external training. As the procedures and technologies are always changing, attending conferences is a great way to stay on top of the latest developments (PSU, 2013).

Other recommendations to promote the organization members to better understand BIM processes and the organization's purpose for using BIM can be:

- A communication website that gives access to documentation, standards, reference manuals and short training videos showing process in practical detail.
- A support forum to answer queries and frequently asked questions plus the ability to share practical experience.
- The Information Managers should have a small support team.
- Specific promotional events outlining the strategy, its benefits, and components.
- A mechanism for all the project teams from client to supply chain sharing innovations, new approaches and technologies (Rail Baltica, 2018).

Defining the training budget and identifying resources

It is critical for the senior leadership to understand the value of training and the activities that should be funded, such as online video training and the time spent creating training materials.

Identifying resources will assist the leaders in determining what needs to be purchased in terms of technology, training rooms, training materials, online video training, and the time required to establish or improve company standards (Roberti and Ferreira, 2021).

[9] Based on the research by Eadie t al. (2013). the primary reason for not adopting BIM on projects relates to the lack of expertise within the project team and external organisations. Therefore, to implement BIM in projects and utilise the full potentials of it, training and education shall be of critical importance.

6. PROCESS[10]

A process is "*a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs: a structure for action*" (Davenport, 1993). This section covers **Process** knowledge cluster that contains **Products and Services** and **Communication** sub-sections.

6.1. Products and Services

This sub-chapter addresses some main subjects related to the purpose of the process itself, to the outputs of that process, to the level of information required as well as to the verification of quality that will assure that the deliverable is in accordance with the requirements.

6.1.1. BIM Uses

6.1.1.1. General overview of BIM Uses

The BIM Uses explain the different ways project stakeholders can use BIM on projects depending on the specific needs they may have. BIM Uses should be aligned with project goals and clearly documented in the BIM Execution Plan.
The following list of BIM Uses in Table 26, organized by project phase[11], are the most common applications of BIM in the company on different projects. It is important to note that not all these BIM Uses would be implemented in every project. Also, the BIM Uses are not limited to this list and there may be other uses for BIM in a project[12].

[10] The current BIM Guide proposal comprises four main knowledge clusters that are presented in four chapters throughout the dissertation. “Process” is the third chapter of the BIM Guide proposal. For more information on the structure of BIM Guide refer to 3.4 Introduction to the BIM Guide Proposal.

[11] The BIM Use topic is covered in 11 out of 19 reviewed guides for this study and half of these guides classify the Uses based on the project phases. Two of them based on the Use type, two of them without classification and one of them divided the Uses to essential and enhanced.

[12] The BIM Uses provided here are the culmination of the Uses existed in the studied resources plus the Uses suggested by the questionnaire respondents.

Table 26 - BIM Use cases

	BIM Uses	Plan	Design	Construct	Operate
1	Site Analysis				
2	Existing Conditions Modelling				
3	Design Authoring				
4	Design Options				
5	Phase and 4D Planning				
6	Augmented Reality				
7	Energy Analysis				
8	Structural Analysis				
9	Lighting and Sun Analysis				
10	Engineering Analysis				
11	Sustainability Analysis				
12	Coordination/ Clash Detection				
13	Codes and Standards Compliance				
14	Design Review				
15	Create Construction Documentation				
16	Site Logistics Planning				
17	Temporary Construction Systems Design				
18	Fabrication				
19	Layout Construction Work				
20	Record Modelling				
21	BIM-to-Field				
22	Snagging				
23	Monitor Maintenance				
24	Asset Management				
25	Space Management				
26	Monitor System Performance:				
27	Quantity take-off and Cost Estimating				
28	Contract Management				
29	Analytics				
30	Safety				
31	Disaster Planning and Management				

6.1.1.2. BIM Uses definitions

All the BIM Uses in the table are described briefly below.

Site Analysis:

A process in which BIM and GIS tools are used to analyse a site to determine the most optimal location, position, and orientation for a future project. Master planning, sun and shadow studies, daylight and solar envelop analysis can be the analysis for the evaluation (CIC, 2015).

Existing Conditions Modelling:

The process of creating a model (geometry and information) of the existing conditions for a site, facilities on a site, or a specific area within a facility. The model can be developed in several ways, including laser scanning, photogrammetry, and traditional surveying methods.

Design Authoring:

The process of using BIM authoring software to develop a model with geometric representation and element properties. The design in the BIM environment can be developed for various disciplines:

- Architecture
- Interiors
- Structure
- Plumbing
- HVAC
- Electrical/Fire Alarm
- Lighting
- Fire Protection
- Telephone/Data

Design Options:

Various versions of a design can be modelled for comparison that allows for more informed decision-making. This can be done through comparing the visuals such as renders and drawings. Also, take-offs extracted from the design options can be used for cost comparisons to support decision making.

Phase and 4D Planning:

A process of using a 4D model (a 3D model with the addition of time) to arrange phased occupancy in a renovation, retrofit, addition, or to demonstrate the construction sequence and space requirements on a construction site. 4D modelling is a powerful visualization and communication tool that can give a Project BIM Team a better understanding of project milestones and construction plans (Messner et al, 2021).

Augmented Reality:

Virtual graphics made by computers and other information projected on a real-world environment that clients can view is known as augmented reality. When the client moves around in the real world, virtual information adjusts automatically to his movements, giving the impression that the virtual information is present. Augmented Reality helps to improvise BIM Service Providers through software, smartphone, or tablet to visualize the 3D Model in a live view of the world (BIM Services, 2019).

Energy Analysis:

A process in which a BIM model is utilised by building energy simulation programs to conduct energy assessments for the building design. By doing energy analysis, the building energy standard compatibility can be inspected. Also, the proposed design can be optimized to reduce the life-cycle costs (Messner et al, 2021).

Structural Analysis

A process in which the behaviour of a structural system is determined by the analytical modelling software. Based on this analysis further development and refinement of the structural design takes place to create effective, efficient, and constructible structural systems (Messner et al, 2021).

Structural design options, overall building structure, and individual detailed connections can be analysed and tested, which can result in a structure which is optimized for cost and performance (Harvard, 2019).

Lighting and Sun Analysis:

Using the model to conduct a quantitative and aesthetic assessment of the lighting conditions in a place or on a surface or set of surfaces. This can include daylighting analysis or artificial lighting analysis (Messner et al, 2021).

Engineering Analysis:

A process in which the BIM model is used to analyse various design alternatives to determine the most efficient engineering solution. The integrated and/or interoperable tools that allow the use of the physical and material properties of project elements, assemblies, and systems within the model for engineering analysis, simulation, and documentation. Examples include structural engineering, wind analysis, daylighting, HVAC, plumbing, fire protection, life safety, and electrical systems design and documentation (NIBS, 2017).

Sustainability Analysis:

A process in which a BIM project is evaluated based on LEED or other sustainability criteria. Applying sustainable features to a project in the planning and early design phases is more effective (ability to impact design) and efficient (cost and schedule of decisions) (Messner et al, 2021).

Coordination/ Clash Detection:

A process in which model elements can be organized and coordinated. In this process, clash detection software can be used to find coordination issues, and to identify spatial design issues a visual analysis can be performed.

Codes and Standards Compliance:

A process in which validation software is used to check the model parameters against applicable codes and standards. Examples may include building code compliance, energy code compliance or accessibility compliance. (NIBS, 2017).

Design Review:

A process in which project stakeholders view the building information model, provide feedback, and validate the various design aspects of a project. Layout, lighting, security, sightlines, ergonomics, acoustics, textures, and colours are some of the criteria for reviewing.

To rapidly assess design options and solve design and constructability issues, a virtual mock-up can be performed in high detail, even on a small fragment of the building, such as the façade (NIBS, 2017).

Create Construction Documentation:

Using BIM to develop the documentation necessary to communicate the facility design to the construction personnel. This may include plans, elevations, sections, renderings, data schedules, 3D diagrams, or specifications (Messner et al, 2021).

Site Logistics Planning:

Developing a model of both permanent and temporary facilities on a construction site to communicate physical site conditions and manage overall logistics during various phases of the construction process. It may also be linked with the construction activity schedule to convey space and sequencing requirements. Labour resources, materials with associated deliveries, and equipment location are examples of additional data that can be added into the model. Because the 3D model components can be directly linked to the schedule, site management functions such as visualized planning, short-term replanning, and resource analysis can be analysed over different spatial and temporal data (Messner et al, 2021).

Temporary Construction Systems Design:

A process to design and analyse the contemporary systems including formwork, scaffolding, temporary shoring and temporary lighting. (NIBS, 2017).

Fabrication:

A process that uses the model as an input into fabrication and manufacturing equipment to produce construction materials and assemblies such as structural steel fabrication, sheet metal fabrication, and wall assembly fabrication.

Layout Construction Work:

A process in which model information is utilized to layout project assemblies. It also can be used to automate control of equipment on a construction project.

Record Modeling:

A process of creating a model that accurately depicts the physical and functional aspects, as well as the environment of a facility and its assets at a given point in time. With the Record Model's ongoing updating and refinement, as well as the ability to store more information, the model now incorporates a genuine representation of space with a link to information, such as serial codes, warranties, and maintenance history of all the components in the building. Eventually, the Record Model also contains information linking pre-build requirements to as built conditions (NIBS, 2017).

BIM-to-Field:

A process of taking the accurate digital data in an information model and using it to inform accurate construction, operations, or maintenance out on site. There are tools that enable you to import model data to a hand-held tablet device in the field (B1m, 2016).

Snagging:

It denotes the process of inspection necessary to produce a list of small defects or omissions in building works for the contractor to rectify (PCSG, 2020b).

Monitor Maintenance:

A process for using facility information models to monitor facility status and schedule maintenance activities for a facility which allows for future prediction and planning (Messner et al, 2021).

Asset Management:

A process in which project data is linked to a Record Model to aid in the maintenance and operation of a facility and its assets. These assets, which include the physical building, systems, the surrounding environment, and equipment, must be well-maintained, improved, and operated in the most cost-effective manner to satisfy both the Owner and the users (NIBS, 2017).

Space Management:

A process for properly distributing, managing, and tracking relevant areas and related resources within a facility using BIM. A model allows the facility management team to analyse the existing use of the space and effectively apply transition planning management towards any applicable changes. Space Management and Tracking ensures the appropriate allocation of spatial resources throughout the life of the facility (Messner et al, 2021).

Monitor System Performance:

Using analytical models and sensor data of a facility to evaluate and model the overall functional performance of facility systems, e.g., structural, mechanical, electrical, plumbing, security, and fire protection (Messner et al, 2021).

Quantity take-off and Cost Estimating:

A process in which a model can be used to generate an accurate quantity take-off which can be used to support cost engineering and procurement activities.
This process provides cost effects of the model modifications, during all phases of the project, which can avoid budget overruns (NIBS, 2017).

Contract Management

A contract can be defined as a written document that specifies the requirements that must be met by parties engaged in the project's execution. In general, a contract is an agreement that guarantees the start of a project. Successful contract management guarantees that the job is executed with the least amount of variance and as close to the contract specifications as feasible[13] (Bimser, 2021).

Analytics

The analytics framework categorizes BIM data as structured or unstructured, provides a set of workflows for applying analysis algorithms based on the data's nature, and includes some machine learning functions, such as deep learning (Jeong, 2018).
key stages of data analytics are:
Data mining – a collection of the desired data from some data source. Of course, Revit projects, models are the source in this instance.
Data processing – Statistical methods, machine learning, and other techniques are used to analyse the data. The goal is to take the raw data from a Revit model or models, structure the data and obtain new relationships, insights.
Data visualization – presenting the processed data in a clear and easy to work with manner, improving collaboration, progress reports with hard data (Invoke SHIFT, 2020).

Safety:

A process in which two types of safety plans can be extracted from BIM model:

1) Internal Safety Measures: A complete safety plan which can result in better communication of requirements and a safer site. Components of a safety plan include Controlled Access Zones, Floor Penetration Protection, and Guard Rail/Perimeter Protection.

[13] This Contract Management linked with the BIM Models and EIR is one of the most enhanced BIM uses mentioned by BIMMS staff. During their daily work, this systematic and permanent relation between the contract and the BIM deliverable is of upmost importance to avoid conflicts and to achieve the goals and expectations.

2) Public Safety Measures: Visuals can be extracted from the BIM to inform the public, communicate upcoming work, and allow stakeholders to interact with the job site. The public safety measures can include Pedestrian Protection and Routes, and Emergency Routes (Harvard, 2019).

Disaster Planning and Management:

A process in which emergency services have access to essential building information in the form of a model and information system. The BIM offers crucial building information to responders in order to improve response efficiency and reduce safety hazards. Building automation systems (BAS), life safety (fire alarm and fire protection), and security systems could provide dynamic (real-time) building information, whereas static building information, such as geometry, floor plans, points of egress and access, and equipment schematics, is stored in a model. These systems are integrated and made interoperable so that emergency responders can link to an overall system. The BIM, in conjunction with the BAS, life safety, and security systems, clearly indicates the position of the emergency within the building, as well as feasible paths to the area and any potentially hazardous spots within the facility (NIBS, 2017).

6.1.2. BIM Deliverables

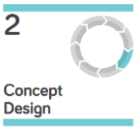
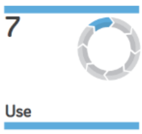
At different stages of a project, some deliverables must be produced to meet a set of BIM objectives. BIM project deliverables should be agreed upon together with defined deadlines at the start of the project.

The deliverables may include a design intent model in both native and open standard format a construction model, and operations and maintenance data. The models, drawings, schedules, simulations, report submissions, and any project specific additions should be documented in the BEP[14].

Table 27 provides the deliverables expected at each submission of the company projects classified by RIBA (2020). The RIBA Plan of Work arranges the process of briefing, designing, delivering, maintaining, operating, and using a building into eight stages. It is a framework for all disciplines on construction projects.

[14] Some deliverables like Cobie data are required to be submitted at different milestones so that they are repeated in more than one phase.

Table 27 - General Overview of Deliverables

Stages	Deliverables
 0 Strategic Definition	Business Case BEP
 1 Preparation and Briefing	Existing Condition Model Site Analysis
 2 Concept Design	Massing Model Construction Strategy Cost Estimates
 3 Spatial Coordination	Zoning Orientation Program and Space validation Drawings 3D Coordination Reporting Quantity Take-off Reporting Engineering Analysis
 4 Technical Design	Detailed Design Models Sustainability Analysis Detailed Energy Analysis System Cost Estimates 3D Coordination Reporting Program Validation Building Regulations Application Shop Drawings COBie Data
 5 Manufacturing and Construction	Construction Models 3D Coordination Validation Cost Estimation Sustainability Reporting Construction System Design Phase Planning COBie Data Digital Fabrication
 6 Handover	Record Models COBie Data
 7 Use	Operation and Maintenance Manual Post Occupancy Evaluation

6.1.3. Lox

The term Lox is used as a generalized term for the numerous LOD-related terms including level of development, level of definition, level of accuracy, level of information, level of geometry, and others.

6.1.3.1. Level of Development (LOD)

The Model Level of Development (LOD) refers to the level of detail with which a model is produced, as well as the model's basic requirements.

According to BIMForum (2020), "*the Level of Development (LOD) Specification is a reference that enables practitioners in the AEC Industry to specify and articulate with a high level of clarity the content and reliability of Building Information Models (BIMs) at various stages in the design and construction process*".

Based on the BIMForum classification, LOD is defined from 100 to 500 as described Table 28.

Table 28 - LOD Specification according to BIMForum (2020)

LOD	BIMForum Specification
100	The Model Element may be graphically represented in the Model with a symbol or other generic representation. Information related to the Model Element (i.e., cost per square foot or tonnage of HVAC.) can be derived from other Model Elements. **BIMForum Interpretation**: LOD 100 elements are not geometric representations. Examples are information attached to other model elements or symbols showing the existence of a component but not its shape, size, or precise location. Any information derived from LOD 100 elements must be considered approximate.
200	The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element. **BIMForum interpretation**: At this LOD elements are generic placeholders. They may be recognizable as the components they represent, or they may be volumes for space reservation. Any information derived from LOD 200 elements must be considered approximate.
300	The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element. **BIMForum interpretation**: The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modelled information such as notes or dimension callouts. The project origin is defined, and the element is located accurately with respect to the project origin.
350	The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, location, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element. **BIMForum interpretation**: Parts necessary for coordination of the element with nearby or attached elements are modelled. These parts will include such items as supports and connections. The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modelled information such as notes or dimension callouts.
400	The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element. **BIMForum interpretation**: An LOD 400 element is modelled at sufficient detail and accuracy for fabrication of the represented component. The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modelled information such as notes or dimension callouts.
500	The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements. **BIMForum interpretation**: Since LOD 500 relates to field verification and is not an indication of progression to a higher level of model element geometry or non-graphic information, this Specification does not define or illustrate it.

The BIM Manager is responsible for assigning an LOD to each element and they must be documented in the BEP.

Refer to BIMForum (2020) for detailed LOD specifications of model elements.

6.1.3.2. Level of Information Need

To prevent delivery of too much information a new concept has been introduced as Level of Information Need. The UK BIM Framework (2021b) defines the Level of Information Need as a "*framework to define the quality, quantity and granularity of information requirements. The level of information need is used to clearly communicate the degree of information required according to its purpose; no more and no less*".

The appointing party defines the Level of Information Need of each information deliverable. Unskilled and inexperienced appointing party is required to at least define the purpose for which the information is needed. In this case, ISO 19650-1 allows the appointing party to receive assistance from prospective lead appointed parties or from an independent third party.

UK BIM Framework (2021b) outlines that the Level of Information Need is defined every time an information requirement is established at different stages throughout the life of an asset. Level of Information Need is a framework for defining information across the facets (purpose, content, form, and format). Information should be defined across the following three sub-divisions:

- Geometrical information
- Alphanumerical information
- Documentation.

An appointing party should specify their information requirements using the level of information need framework defining:

1. The purpose why information is needed
2. The Geometrical information to fulfil the purpose
3. The Alphanumerical information to fulfil the purpose
4. The Documentation to fulfil the purpose.

6.1.4. Quality Control

6.1.4.1. General Quality Control Strategy

Quality Control Checks are significant to the BIM projects as the lack of quality controls results into inaccurate and incomplete BIM models. Quality Checks should entail checking on the geometric and nongeometric information of a BIM model. As well as the flawless graphical representation, the embedded data in the BIM models are expected to be perfect, clear, and precise.

A quality control plan for BIM models should be established by the BIM Manager/Coordinator, based on regular inspections. The quality control plan should be based on an agreed set of rules, procedures, and requirements of this Guide. Each project member should be in charge of performing quality control checks on their deliverables prior to submission.

6.1.4.2. Various Kinds of Inspection

Validation should be implemented in the following areas:

• geometrical representation and spatial position,

• data,

• 3D coordination.

To validate the BIM models in these areas, four types of Quality Checks should be performed throughout the project cycle:

-Visual Check

By doing a visual check of the BIM model, each component of the model is reviewed comprehensively to make sure that proper design steps are followed.

-Clash Check

Performing a clash check, the interferences between model elements would be detected. See “Clash Detection” section for more details.

-Data Check

Crosschecking is done between client’s data and data inserted in the software while creating BIM models. It must also be ensured that the datasets are populated with correct data and according to the defined Level of Development for that design stage and that the file format and naming conventions are conform the project Data Exchange protocols (Rail Baltica, 2019)

-Standards Check

A technical verification that checks the compliance of the design against the technical design guidelines for each discipline.

6.1.4.3. Quality Control Workflow

In the Table 29, there is a brief description for each Quality Control check. The responsible party and the frequency of conducting each check are also outlined.

Table 29 - Quality Control summary

CHECKS	DEFINITION	RESPONSIBLE PARTY	RECOMMENDED FREQUENCY
Visual Check	Compliance to the design intent	BIM Specialist - Modeler/ Discipline coordinators	Continuously
Clash check	Detecting conflicts between two elements.	Discipline coordinators	Weekly
Data Check	Ensure that the project data has no undefined, incorrectly defined elements	Discipline coordinators	Continuously
Standards Check	Ensure that the applicable technical standards have been followed	BIM coordinator	Weekly

The table below presents instances of the checks for each type. The checks should include but not limited to the followings:

Table 30 - Instances of various check types

TYPE OF CHECK	INSTANCES
Visual Check	Model coordinate and orientation No unnecessary component in the model The compliance with defined LOD Coordination between Native and IFC files Ensure design intent has been followed Model files are up to date, containing all users' local modifications Model files are detached from central file All floor levels defined and uniquely named The building sections are completely dimensioned and annotated
Clash check	Interferences between elements. See "Clash Detection" section
Data Check	Crosschecking between client's data and data inserted in the software File format, naming conventions and folder structure Using the standard project template Verify the structure of IFC files
Standards Check	The compliance of the design against the technical design guidelines for each discipline and established classification for example UniClass

6.1.4.4. Checking the Model

All checks are conducted either manually or automatically using different software (Revit, Navisworks, Solibri, Microsoft Excel and others).

Manually reviewing a large number of components with several parameters can be inefficient, labour-intensive, and prone to negligence. Moreover, the owner should hire personnel with relevant BIM skills to perform the work (Pishdad-Bozorgi et al., 2018). However, automated model checking using software tools makes the validation feasible even for inexperienced users of BIM.

The automated model checks can identify whether required information is present in the model and is in a valid format. Similarly, automated model checking can detect whether field values match those in a pre-defined lookup list. Automated model check reports will show different categories of errors, and reviewers will need to determine which errors are attributable to model-checker software issues, which errors are related to file exports from the native model to IFC, and which errors are due to actual issues in the native file. However, automated model checking will not be sufficient to determine if the data in the fields correctly conveys design intent for a specific project. This type of checking would need to be done manually by someone familiar with the project scope. This manual model checking would be similar in intent to traditional design review activities (GSA, 2016).

6.2. Communication

6.2.1. Information Exchange and Collaboration

The implementation of the BIM information exchange process may result in a new perspective on how to manage and coordinate the information on projects. The BIM Manager would be responsible for maintaining and sharing the information exchange sheet with the various team members, depending on their roles and responsibilities. The information exchange sheet must remain as one version of the truth and be managed in the Common Data Environment (CDE) (Mccann, 2017). Defining Information Exchange protocols is one of the main components of BEP.

The success of construction projects is determined by the parties involved and how well they collaborate to achieve both their own and the project's goals. Collaborative working requires us to communicate and be transparent with each other, to plan what we are doing as a team (UK BIM Alliance, 2019). The ability to effectively exchange, reuse, and share data without loss or misinterpretation is a critical component of collaborative environments.

6.2.1.1. Data Drops

To ensure projects are properly validated and controlled as they develop, data is extracted from the evolving building information model and submitted to the appointing party at key milestones. A **'data drop'** or **'information exchange**' is the term used to characterize this data submission. In most cases, data drops correspond to project stages, and the information required reflects the stage at which the project should have reached. This could be compared to a stage report on a traditional project. The nature of data drops should be set out in the Exchange Information Requirements (EIRs). The EIRs may be considered to sit alongside the project brief. Whilst the project brief defines the nature of the built asset that the employer wishes to procure, the EIRs define information about the built asset that the employer wishes to procure to ensure that the design is developed in accordance with their needs and that they are able to operate the completed development effectively and efficiently (PCSG, 2020a).

Data drops are likely to include:

- **Models** (Industry Foundation Classes (IFC) models and native project information models).
- **Data structures** (such as COBie files and schedules).
- **Reports** (typically PDFs, although native files can be more useable).

PAS 1192:2 *Specification for information management for the capital/delivery phase of construction projects using building information modelling*, proposes for the project phases:

1. Brief.
2. Concept.
3. Definition.
4. Design.
5. Build & commission.
6. Handover & closeout.
7. Operation & in use.

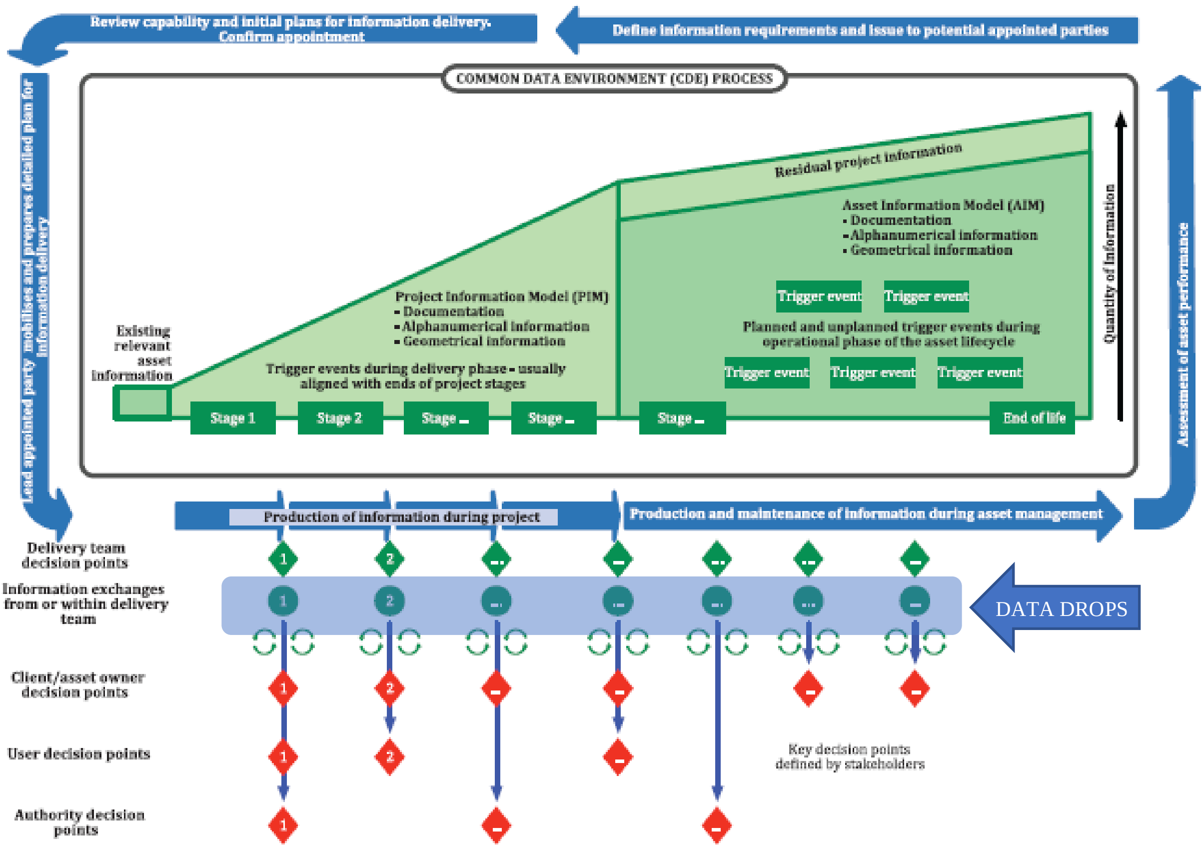


Figure 15 – Information exchange and data drops at different project stages. Adapted from (BSI, 2019a)

6.2.1.2. Review Process

To ensure the project workflow is maintained, regular reviews should take place. These reviews guarantee the model integrity and achieving the project requirements.

6.2.1.2.1. Project Kick-Off

A BIM Kick-Off meeting will be held at the start of the project. The meeting's goal is to figure out how the project's information requirements will be fulfilled and to establish the project's BIM Execution Plan. The BIM kick-off meeting should include all important stakeholders and address the information requirements for the project's whole lifespan early on. As a starting point, the agenda for the kick-off meeting might be based on the headings addressed in the Project BIM Execution Plan.

6.2.1.2.2. Review Meetings

A BIM-based project's success depends on effective and consistent communication. Regular BIM project meetings, which continuously monitor the project to ensure that project BIM requirements are met and that BEP is followed, are urged to help with this (AEC(UK), 2015). Regular meetings to discuss areas of concern shall happen as requested by the Lead Engineer/Architect. To facilitate the discussion, copies of pertinent Revit RVT files or their corresponding Navisworks NWC derivatives should be accessible via Livelink and displayed on a screen viewable by all attendees (PANYNJ, 2019).

6.2.1.2.3. Model Coordination Meetings

Coordination between disciplines and/or trades requires special attention. Coordination should be a conscious effort throughout the design process and construction processes. Coordination review meetings are an integral part of the company BIM process. Coordination meetings shall be held on a recurring basis starting six weeks after project kick-off. These meetings will be centred on the results of the coordinating process. A meeting leader and at least one person from each discipline who is directly involved in the project design are required to attend the meetings. Each meeting will involve a live walk-through of the composite model and result in a clash report detailing (PANYNJ, 2019).

6.2.1.2.4. Progress Tracking

To review the general development of the BIM model files, progress meetings should be held regularly. These sessions may vary in frequency as the project proceeds, but they are an important aspect of a successful BIM project. Progress in developing geometry and/or adding data to the files and evaluating the level of completeness of the models are the topics that may be discussed in these meetings. Also, any implementation challenges that team members may be encountering should be addressed.

Major reviews carried out at key project stages to verify that projects should be allowed to progress to the next stage.

6.2.1.3. Common Data Environment (CDE) for Collaboration

6.2.1.3.1. Definition of CDE

This Guide is aligned with ISO 19650-1 Collaborative Working, which defines the process for design collaboration and efficient data sharing in Common Data Environment.

A common data environment (CDE) is defined in ISO 19650-1 as "*agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process*". Based on ISO 19650-1, a CDE workflow describes the processes to be used and a CDE solution can provide the technology to support those processes. The appointing party is accountable for ensuring this CDE is implemented, configured, and supported throughout the project.

6.2.1.3.2. Functional sections of the CDE

There's a risk that people think the CDE is all about technology and not so much about workflows. In fact, it is fundamental that workflows are developed first, and solutions are selected to facilitate the workflow (UK BIM Framework, 2020). It is this combination of 'Solution' and 'Workflow' that principally defines the CDE. In Figure 16 taken from ISO 19650-1, this concept is depicted in a simple graphical form whereby information exists in various states including Work In Progress, Shared and Published, whilst continuously archiving the information (UK BIM Alliance, 2019). In working with files collaboratively, some kind of workflow/ sign-off process should be considered, so it is clear which information remains work in progress, which has been shared (following appropriate review) and which published (following stakeholder sign-off). The versioning of assets and archive for those that have been superseded also should be considered (McPartland, 2016).

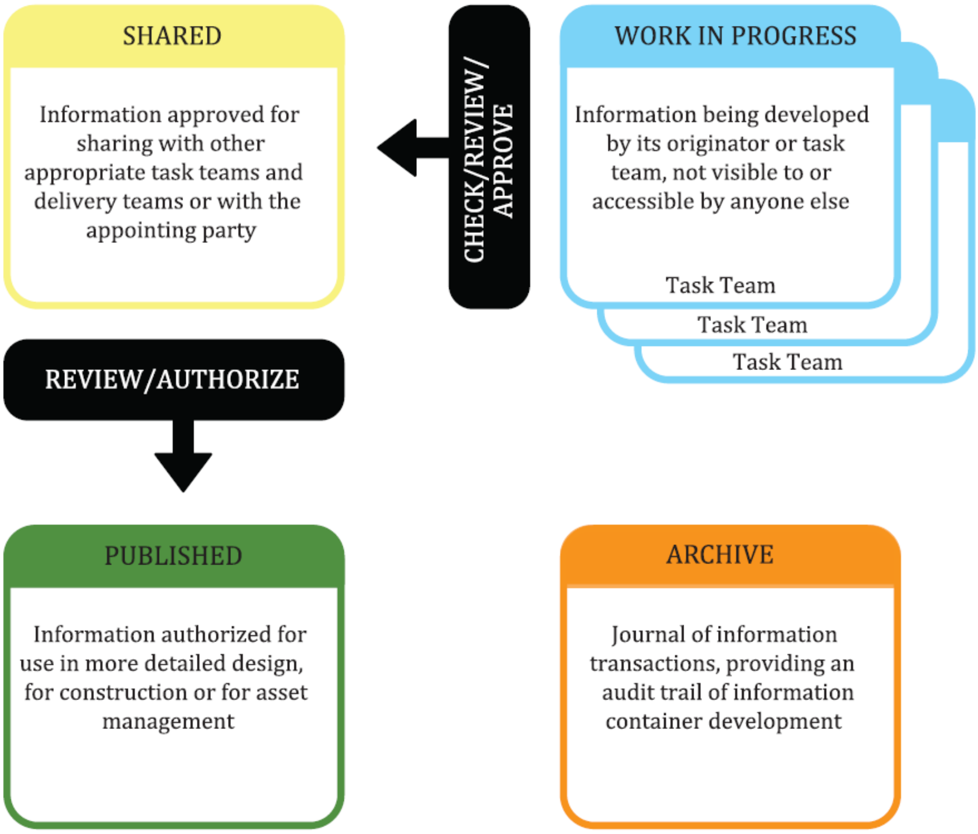


Figure 16 - Common data environment (CDE) concept ((BSI, 2019a)

6.2.1.3.3. The Objectives and Benefits of a CDE

The CDE fundamental objectives of CDE:

1. 1. To provide everyone with up-to-date, reliable information in a structured, user-friendly format.

2. Support the management, creation, assurance, sharing, dissemination, and co-ordination of information generated during major works, minor works, and maintenance activities (Mordue, 2018).

The benefits of CED:

- Supports more efficient processes in the creation and management of information.
- Improves communication and coordination between teams reducing time and improving outcome.
- Assures data ownership by preserving the right for the originator to be the only person authorised to change the data.
- Supports analysis and model optimization.
- Facilitates the process to gather and reissue information.
- Reduces the risk of information duplication.
- Reduces the time and effort required to check and version information.
- Assures the use of the latest version of the models /information.
- Assures data reliability and reduces risk.
- Tracks the information flow through data revisions and versioning.
- Provides the possibility to increase the data storage as an online platform.
- Provides constant access to reliable and relevant information.

- Assures a safe and accurate information transfer among the project's phases.
- Saves time to transfer information among the project's phases.
- Permits information storage and information retrieval.
- Enables managing processes and maintenance planning for the future use of the building.
- Supports improved analysis across portfolio of built assets.

6.2.1.3.4. Adoption of CDE within industry

There are various software vendors around the world developing CDEs so that the number of CDE platforms is constantly increasing. These CDE platforms allow for the uninterrupted flow of information using industry file formats (IFC) or a native file format including Autodesk, Graphisoft, Bentley, etc. Despite the use of the IFC format and the COBie schema, there is still difficulties to pass information from one authored platform to another without downloading it to a local server. As previously mentioned, the appointing party is responsible for the CDE implementation. This can result a company to have different CED platforms for each of its projects. Therefore, specific training at the beginning of each project is required for the BIM Manager, the Information Manager, and all the team members to achieve the high level of information exchange and consistency in the CDE.

The company may use the CDE Matrix comparison analysis (Table 31) developed by Terrosi (2020) to support the appointing party to choose the appropriate CDE. The criteria for evaluating each CDE platform are:

User-friendly Interface: an intuitive use of the platform simplifies information storage, thanks to a better comprehension of the environment and structure. A different interface/environment to manage drawings and documents could help differentiate, inside the same platform, the design-construction phase, and the maintaining and operational phase, as well as the information management phase.

- Secured login and access privileges: it should be possible to set permissions to log into the server and give access to the folders according to the project's role, as per RACI matrix agreed in the BEP.

- Controlled access to the BIM-server: in every building, during the project's lifecycle, roles could increase, and overlap compared with the ones planned at the beginning. To facilitate this process, it is essential to provide features that allow to add permissions and access rights to the server.

- Hierarchical customisable structure: each CDE is designed using a hierarchical model, but clients or companies might want to be able to customise this structure according to their requirements.

- Nomenclature editor: the platform should be provided with the option to change the nomenclature system during the process whenever needed, and to maintain edit rights.

- Data management and notification: during the modelling and coordination phase, some issues may rise while the single disciplines models are merged in the federated model. To maintain a high-level of coordination, the CDE software should send a notification to its members every time a new file is uploaded. It should also build a downloadable backup folder to maintain track of previous versions of the model, eliminating the risk of losing all of your work if something unexpected happens.

- Reporting: it is important to be able to address, inside the platform, the model/drawing and documentation issues to each team.

- Upload and download model: upload and download task team models in the IFC format, to link them to the user model for better coordination.

- Visualisation, Navigation and Model View Definition: it is important to support the Design Stage and the revisions to filter information according to needs.

- Library: it should be available the possibility to store objects in a shared folder, to be used in the project or stored for future needs.

- Model repository: the platform should have a repository where to store and retrieve information for future use. Or better yet, should allow for the possibility to link that repository folder to others, may these be from the same developer or not.

- Interoperability: it should use common formats to exchange information (IFC, BCF, COBie), to have information consistency.

- Training: the provider should supply training for the platform and inside the CDE there should be a dedicated area for FAQ and small video tutorials to support users to a correct use of the platform.

As Terrosi (2020) stated the developed matrix was structured by listing the platforms to evaluate in the rows and the evaluation criteria in the columns. The only exception is the first row, dedicated to the BIM Manager. Being the one who better understand the requirements needed by the client, the other stakeholders, and the project, they will be able to set priorities for the criteria. To do that, they can give a score weight evaluation to each criterion (0-10), to be assigned according to the project and the teams' needs. Criteria could be added according to different needs. The last column shows the average assessment according to the BIM Manager scores and the platforms' features. In case of a tie in the evaluation between platforms, the BIM Manager may make his decision based on the 'Price' column. The attribution of 'Yes' or 'No' platform evaluation is only used as an example. A gradient of colour was used to quickly identify the platform which better accomplishes the project's needs according to the BIM Manager evaluation. White cells correspond to the lowest grade, while dark blue ones to the highest.

Table 31 - CDE comparison matrix. (Terrosi, 2020)

CDE Comparison Matrix																			Max Score
BIM Manager	Score evaluation according to project's needs		3	10	7	4	4	3	6	6	5	4	1	10	9	5	8	5	90
Platform	Developer	Price	User-friendly Interface	CDE core structure according to PAS 1192	Secured log in and access privileges	Controlled access to the BIM-server	Hierarchical customisable structure	Nomenclature editor	Data management and notification	Reporting	Upload and download model	Visualisation, Navigation and Model View Definition	Library	Model repository	IFC	BCF	COBie	Training	Average
Platform 1	Developer 1		Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	86
Platform 2	Developer 2		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	90
Platform 3	Developer 3		Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	84
Platform 4	Developer 4		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	80
Platform 5	Developer 5		Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	66
Platform 6	Developer 6		Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	60
......	.....																		

Table 32 presents some CDE platforms available in the market. The company may use the CDE Matrix comparison analysis (Table 31) to choose the most applicable platform from the following list for the organization or a specific project.

Table 32 - CDE Platforms in the market

Platform	Provider	Website
AEC Hub	AEC Hub	https://aechub.io/
Allplan Bimplus	Nemetschek	https://www.bimplus.net/index.php
Asite	Asite	https://www.asite.com/
Autodesk BIM 360	Autodesk	https://www.autodesk.com/bim-360/
Bentley Projectwise	Bentley	https://www.bentley.com/en/products/brands/projectwise
BIMaaS platform	BIMaaS	https://www.bimaas.uk/
BIMCloud	Graphisoft	https://graphisoft.com/solutions/products/bimcloud
BIMcollab Cloud	BIMcollab	https://www.bimcollab.com/en
Bimsync Arena	Bimsync	https://bimsync.com/
BIMXtra	Clearbox	https://www.clearboxbim.com/products/bimxtra
EcoDomus	EcoDomus	http://ecodomus.com/
Groupbc	Bentley	https://www.groupbc.com/
Oracle Aconex	Oracle	www.oracle.com/
Procore	Procore	www.procore.com
Revizto	Revizto	https://revizto.com/en/
Techture planBIM	Techture	www.planbim.io
Trimble Connect	Trimble	https://connect.trimble.com/
Viewpoint	Viewpoint	https://www.viewpoint.com/
3D Repo	3D Repo	https://3drepo.com/

6.2.1.4. Cloud/Mobile BIM for Collaboration

The construction sector has experienced a tremendous surge in the use of mobile/cloud BIM computing technology in construction projects over the last few years. It has been used to facilitate collaborative communication on mobile devices such as PCs, smartphones, tablets, and iPads. BIM is being combined with cloud computing technology to create a new working pattern that streamlines communication with the onsite processes. Indeed, cloud computing technology promises to offer enhanced accessibility of project data and site images simply by remotely linking mobile devices with a dedicated remote server. The mobile/cloud BIM technology promises to offer higher levels of cooperation and collaboration. One of its major strengths is in the ability to offer a real-time communication platform for project team members and other external stakeholders (Abanda et al, 2018).

Mobile/cloud-BIM technology provides:

- Real time monitoring of progress.
- Coordination.
- Clash detection.
- Data sharing amongst project teams regardless of location, inter alia.

6.2.2. Clash Detection

6.2.2.1. General Overview

The appearance of clashes during the design or the development of the BIM models is inevitable. The aim of the clash-checking is to utilize automatic interference checking software to resolve design interferences between the elements, particularly between different design disciplines, so that coordination errors on site are eliminated and the model is free of constructability issues. When objects or components are not spatially or geometrically coordinated and conflict, the term clash or interference is used. Project participants should share their models with other project members for reference at regular intervals beginning with design and continuing through construction. Models from various disciplines should be coordinated at certain milestones, allowing relevant parties to settle potential conflicts ahead of time and avoid costly abortive effort and delays during the construction stage.

The clash-check is performed by the BIM Manager, BIM Model Coordinator, or a qualified BIM Modeler. The result of the check must be documented in a report (BCF is recommended- see 6.2.2.10 for more information on BCF) and whether communicated to the other disciplines or discussed at the collaboration meetings, where the resolution of clashes will be recorded, and the extent of any necessary follow-up will be agreed. The result of clash detection must be communicated to the designers responsible for the individual disciplinary models to enable them to perform the necessary corrections. They will continue to be in charge of incorporating these corrections. Throughout the design phases, the team will check the model (Model Review) and any remaining clashes in Model Review meetings as needed (usually weekly) until all spatial and system coordination issues are resolved. BIM manager is responsible to federate the clash-free discipline models and perform the clash detection to find the conflicts in the federated model. The clash report should be communicated to the responsible disciplines to be resolved. This process iterates as shown in Figure 17 to ultimately reach a so-called clash-free model.

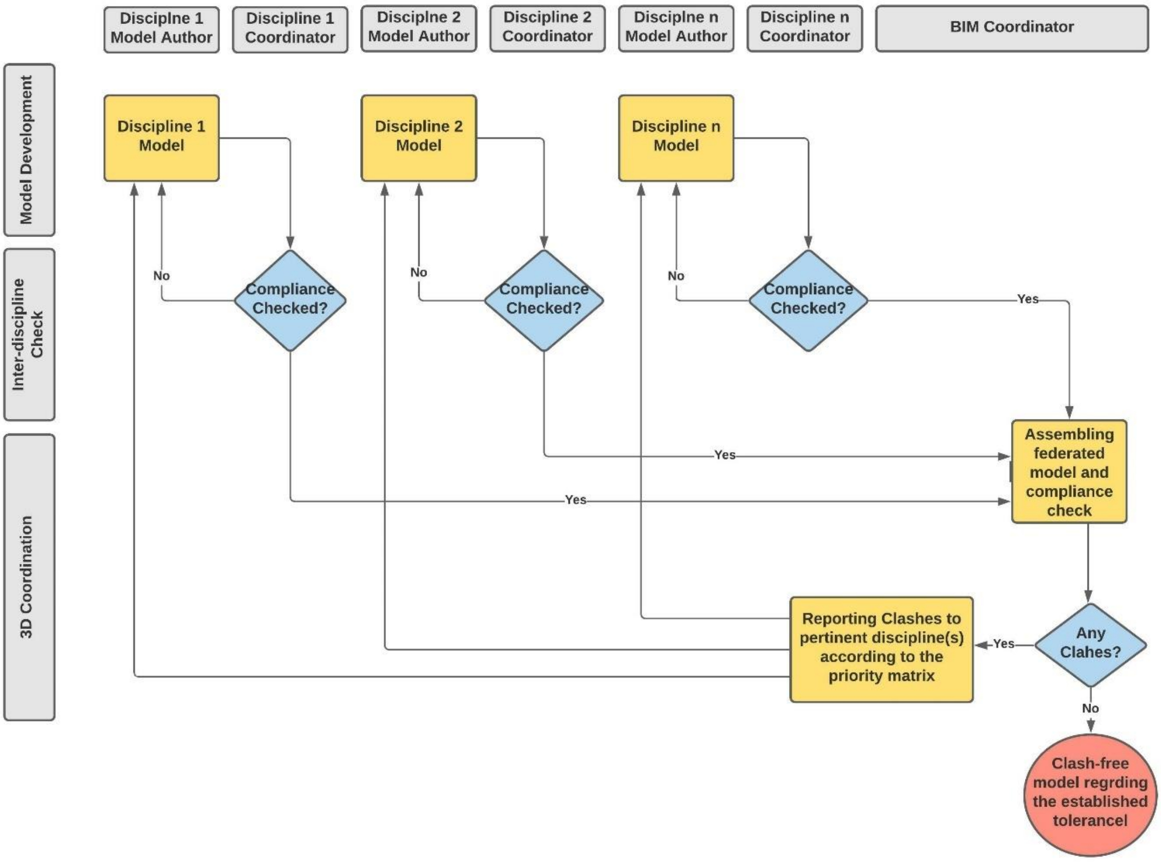


Figure 17 - Clash detection process map

6.2.2.2. Clash Types

There are different clash test types that may vary in naming depending on the software used for the Clash check:

Hard clash: two objects / components occupy the same space, in other words, those objects intersect (Figure 18).

Soft clash: two objects / components do not intersect but do not fulfil a spatial rule between them. The most common rule is the distance between the objects' geometries, such as clearances, tolerances or if correctly set up, standard regulations checks (Rail Baltica, 2019).

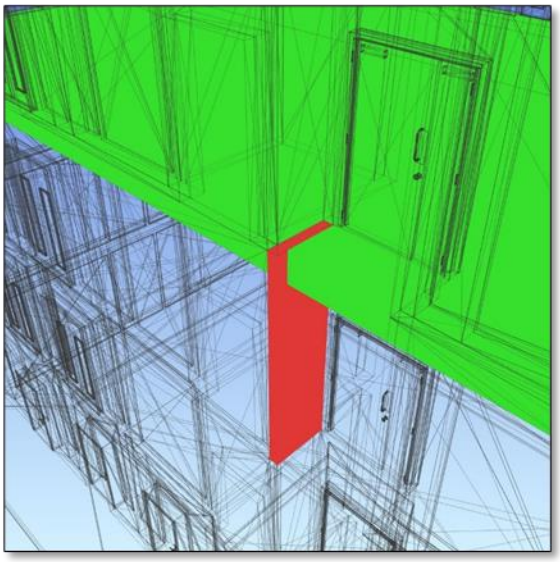


Figure 18 - An example of hard clash, wall, and floor intersecting

6.2.2.3. Clash Checking Scope

Single-Discipline Check

The Single-Discipline Check will be performed by each Discipline's Leader using the Interference Check tool such as Solibri Model Checker or Navisworks which is defined in the BIM Execution Plan.

The issues found by performing the single-discipline checks can be internally resolved by a single entity (consultant or subcontractor) independently. The goal is to reduce error propagation in the design and to ensure compliance with good design practices and applicable codes and regulations (GSA, 2016).

Cross-Discipline Interference Check

The BIM manager is responsible of scheduling Inter-Disciplinary Interference Check Sessions as needed by the project, which is usually specified in the BEP.

The clashes found by performing Cross -Discipline checks require coordination between multiple entities (consultants or subcontractors) within a single contract. For example, it could be a clash between the structural and mechanical engineering designs. The goal is to reduce the number and impact of field changes during the construction phase of the project (GSA, 2016).

It is important to note that not all the conflicts detected are problems. Certain interferences are intentional and part of the modelling process. Examples of acceptable clashes are embedded pipes, switches, and recessed lights within walls.

6.2.2.4. Clash Matrix

To ensure that all cases are assessed, and the result is a clash-free model, a Clash Matrix should be established and agreed upon internally.

6.2.2.5. General Clash Matrix

Table 33 is an example of a general clash matrix of discipline models against each other to define the clash tests between what disciplines are supposed to be performed.

Table 33 - Clash matrix

X= to be performed	Architecture	Structure	Electrical	Mechanical	Plumbing	Ventilation	Geotechnical
Architecture	X	X	X	X	X	X	X
Structure		X	X	X	X	X	X
Electrical			X	X	X	X	X
Mechanical				X	X	X	X
Plumbing					X	X	X
Ventilation						X	X
Geotechnical							X

After the collision detection process, the next step is to assign specific clashes to a specific trade, person, or project group that will be responsible for a given clash. However, it is not an easy task to find the responsible for a clash. To deal with this problem, system hierarchy can be used.

6.2.2.6. Building System Hierarchy

During the construction of the building, there is a hierarchy of systems that occur sequentially one after the other. This hierarchy is nothing more than a mechanism to categorise the various building systems, from those that are most difficult or expensive to move to those that have the greatest freedom of movement (Lozinski, 2021).

For each project, depending on the type of the project, the coordinator decides the hierarchy and the order can be different, but in typical construction projects, it may look like the Figure 19.

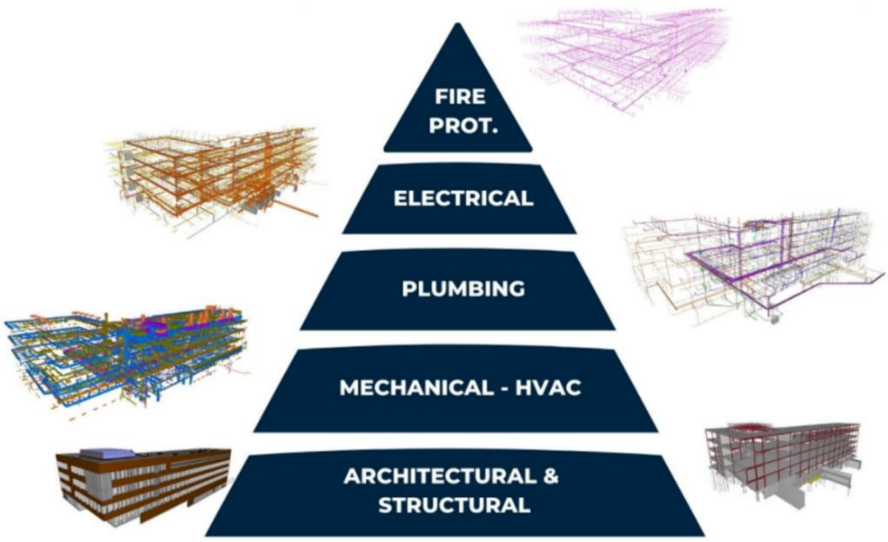


Figure 19 - Building System Hierarchy (Lozinski, 2021)

First and at top of the pyramid, structural and architectural elements are created as the core of any construction. Unless there is a major issue, they will not move.

Then there are components and systems that are bound to the location of specific rooms in the building for example toilets as well as huge objects with the little possibility of relocation in the later stages of design such as the main mechanical ducts.

In the next stage, there are systems like plumbing or smaller ducts and pipes that have a greater ability to adjust their position in relation to the other elements.

And last, electrical systems, fire protection, and other minor systems are positioned which are flexible and their placement can be relatively easily adjusted.

As stated above, despite this general hierarchy, for each project, a specific hierarchy can be defined. For instance, if on a particular project the fire protection system needs to be embedded in concrete for aesthetical purposes, probably the clash/interference with this specialty should come down in the hierarchical pyramid.

6.2.2.7. Clash Matrix with System Hierarchy

The clash matrix using system hierarchy (Table 34) demonstrates which disciplines take precedence based on which ones are furthest to the top of the matrix.

Table 34 - Clash Matrix with System Hierarchy

	Architectural	Structural	Mechanical	Plumbing	Electrical	Fire Protection
Architectural	1	3	6	10	15	21
Structural		2	5	9	14	20
Mechanical			4	8	13	19
Plumbing				7	12	18
Electrical					11	17
Fire Protection						16

In the matrix, each discipline is responsible for the internal coordination of its disciplines, and it is marked with red numbers. The numerical order determines the order in which clash detection occurs. So, the architectural and structural models are first in the order to be analysed. This matrix shows the priorities and helps us to find the responsible trade.

Each discipline is responsible for all checks from its column. For example, the mechanical trade will be responsible for fixing clashes of mechanical equipment with architectural and structural models (as shown on the matrix).

It is worth noting that the hierarchy is a concept to facilitate coordination process and it is not certainly applicable to all clash cases.

6.2.2.8. Detailed Clash Matrix

The matrix above provides a general overview of multidisciplinary collision detection. For complex projects requiring very precise checks, a detailed type of matrix can be defined to check elements of each discipline against each other as shown in Table 35.

Table 35 - Detailed Clash Matrix for checking model elements against each other

Clash Detection		Architectural			Structural			Mechanical			Plumbing			Electrical		
		Walls	Floors	Doors	Columns	Slabs	Roofs	Air Terminals	Ducts	Mechanical Equipment	Plumbing Fixtures	Pipes	Pipe Fittings	Lighting Fixtures	Electrical Equipment	Cable Trays
Architectural	Walls															
	Floors															
	Doors															
Structural	Columns															
	Slabs															
	Roofs															
Mechanical	Air Terminals															
	Ducts															
	Mechanical Equipment															
Plumbing	Plumbing Fixtures															
	Pipes															
	Pipe Fittings															
Electrical	Lighting Fixtures															
	Electrical Equipment															
	Cable Trays															

6.2.2.9. Clash Detection Process in the Software

The automated check process is composed of:

− Creating a clash test

− Selecting elements for checking

− Setting test criteria and options

− Running the test

− Creating clash check reports

6.2.2.10. BIM Collaboration Format (BCF)

BIM Collaboration Format (BCF), initiative of buildingSMART, is an open standard for exchanging coordination information to enhance collaboration between the project team members. BCF provides a standard protocol for communicating a model-driven environment. Figure 20 depicts the procedure for identifying and resolving coordination issues and clashes in model data using BCF. From the point of view of the number of BCF files used, multiple approaches can be used: one BCF per discipline, one BCF file per model, one BCF file per discipline and physical subdivision (Rail Baltica, 2019).

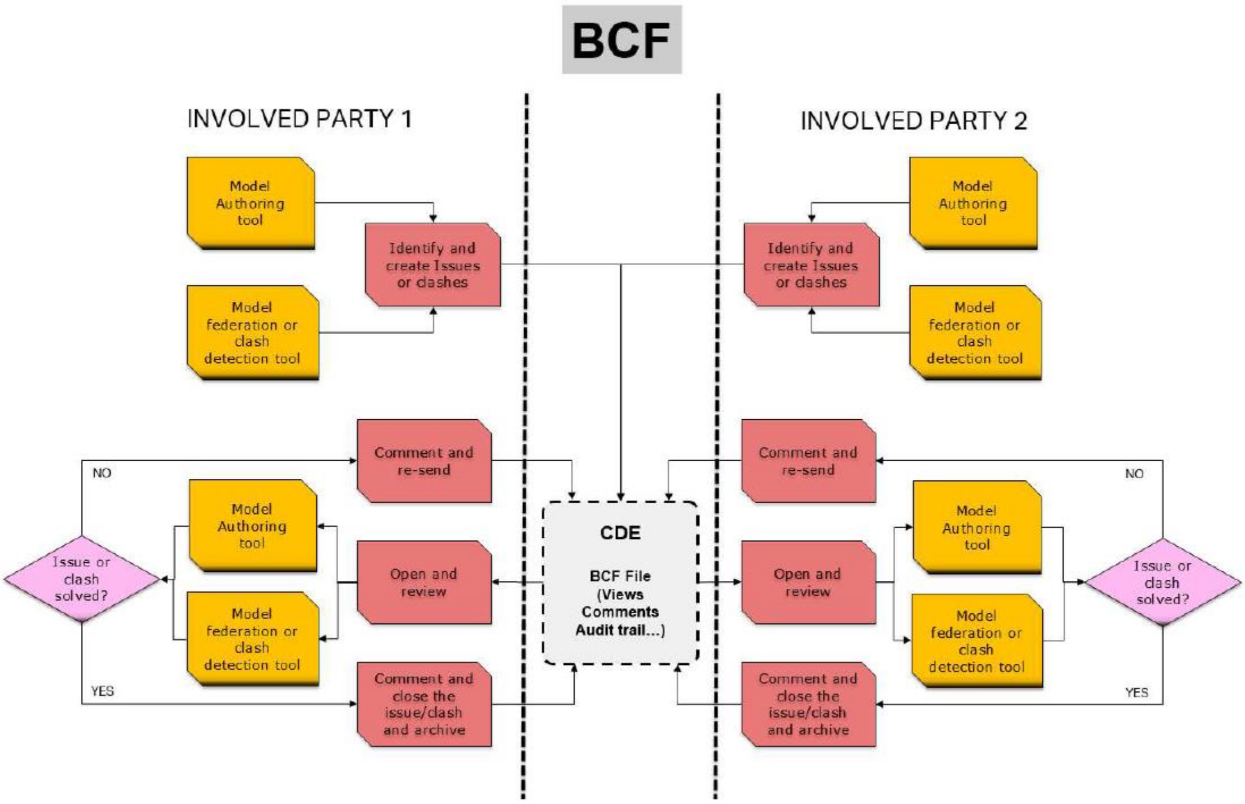


Figure 20 - Example of general BCF communication workflow (Rail Baltica, 2019)

6.2.3. Construction Operations Building Information Exchange (COBie)

6.2.3.1. Definition of COBie

COBie (Construction Operations Building Information Exchange) is a non-proprietary data format for publishing a subset of building information models (BIM) that focuses on asset data rather than geometric information. It is formally defined as a subset of the Industry Foundation Classes (IFC - the international standard for sharing and exchanging BIM data across different software applications) but can also be conveyed using worksheets or relational databases (PCSG, 2021).

6.2.3.2. COBie Worksheet

COBie is usually in the form of an excel file (.xlsx) that organizes project information into distinct categorized worksheets and is exported from a BIM model. COBie does not create a greater demand for information; rather, it organizes it in a more accessible format that makes data easier to use and repurpose. The format is intended to be easy to manage by any organization, irrespective of size and IT capability. Because of its simplicity, all tiers of the supply chain are able to contribute to the data set, even by simply entering it into the spreadsheet. In addition, the format protects the client against extra complexity, changes in technology, interoperability challenges, and proprietary software issues. COBie is composed of multiple sheets that explain the facility's attributes, systems, and assets, as well as product categories, warranties, and maintenance requirements. Additional attributes, issues, and documentation can be connected with specific items as the project progresses (PCSG, 2021).

6.2.3.3. COBie Worksheet Content

A COBie file contains twenty worksheets which can be separated into three main categories namely "design", "build" and "common". Two worksheets namely "Instruction" and "PickLists" are excluded from the schema shown below (Figure 21 and Table 36) because they are for reference only. Project information should first be properly defined, inputted, and updated directly in a BIM model before exporting COBie worksheets. Then, project information can be generated automatically in different categorized worksheets (DSD, 2019).

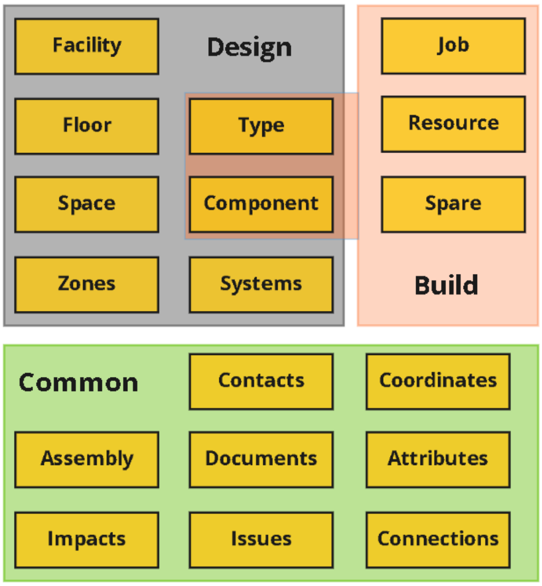


Figure 21 - COBie worksheets and their categories. Adapted from (DSD, 2019)

Table 36 - The Structure of the COBie Data Model and the key information in each worksheet

The Structure of the COBie Data Model	Worksheet	Key Content
The core- **Design**	Facility	building, site, and facility
	Floor	Vertical levels
	Space	Spaces, rooms, areas
	Zone	Sets of space sharing a specific attribute
	Type	Types of equipment, products, and materials
	Component	Individually named or scheduled item
	System	Sets of components providing a service
Subitems describing the types- **Build**	Job	Safety and other job plans
	Resource	Required materials, tools, and training
	Spare	Onsite and replacement parts
The common items- **Common**	Assembly	Constituents for Type, Component, and others
	Impacts	Economic, environmental, and social impacts
	Contacts	various stages of a project life cycle
	Documents	All applicable document references
	Issues	Other issues remaining at handover
	Coordinates	Spatial locations in box, line, or point format
	Attributes	Properties of referenced item
	Connections	Logical connections between component

6.2.3.4. COBie as a requirement

The COBie standards were created with the intention of being included in/referenced in construction, design, and product delivery contracts. However, just a simple reference to a version of the COBie standard is not enough and it is needed to specify:

- what objects require maintenance and therefore should be included in the export
- What classification system to use
- What custom properties to use for each item
- If (and how) it is wanted to track relations to the BIM models, for example ifcGUIDs
- How the delivery process will be (continuous, data drop per phase-change or just as part of the handover)
- How the collection and coordination process will be. Will either the owner or the main contractor hires someone to coordinate the process. (Will it be the BIM manager, Will it be the Architect, etc.) (Grani, 2016).

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7. TECHNOLOGY[15]

Technology is "(1) *the practical application of knowledge especially in a particular area, or (2)a manner of accomplishing a task especially using technical processes, methods, or knowledge*" (Merriam-Webster, 2021). This section covers the **Technology** knowledge cluster that contains **Technical standards** and **Software** sub-sections.

7.1. Technical Protocols

7.1.1. Folder structure

This section specifies how BIM data should be saved in the project folder structure. Regardless of project size or nature, all project model files, drawings, references, and data must be organized and filed in a uniform folder structure on a central server. To ensure that backup and disaster recovery services are available to secure the models and databases, all models should be saved on a central server. The System Administrator should standardize and set up the subfolder structure under the central server.

7.1.1.1. Central Resource Folder Structure

The Central Resource Library, which will be server-based and have restricted write access, will store standard templates, drawing borders, object definitions, and other non-project specific data (Figure 22).

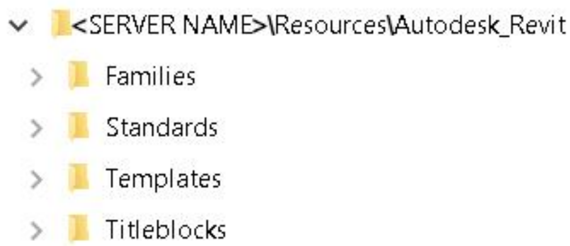


Figure 22 - Central resource library folder structure

7.1.1.2. Local Project Folder Structure

Local copies of central project models do not need to be backed up as changes are regularly synchronized with the central file(s). They shall be stored on the user's hard drive – not in "My Documents"– in the folder structure shown in Figure 23.

[15] This BIM Guide proposal comprises four main knowledge clusters that are presented in four chapters throughout the dissertation. "Technology" is the fourth and last topic discussed in the BIM Guide proposal. For more information on the structure of BIM Guide refer to Introduction to the BIM Guide Proposal.

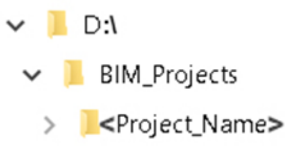


Figure 23 - Local project folder structure

7.1.1.3. Example Project Folder Structure

The folder structure illustrated below is as an example arrangement. This structure is recommended to be used to deliver the appropriate files, object libraries, and drawings for submissions. The defined structure follows the principles of ISO 19650-1 ‘Work In Progress (WIP)’, ‘Shared’, ‘Published’ and ‘Archived’ segregation of data within a designated set of folders.

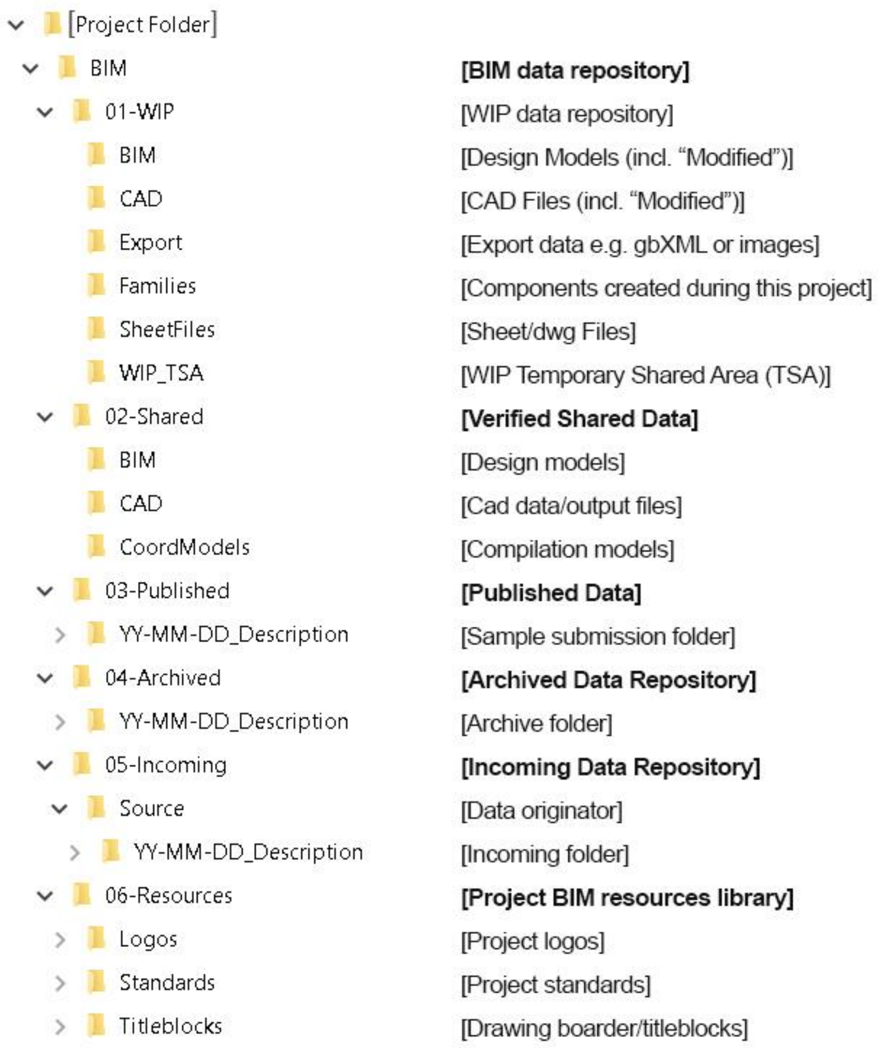


Figure 24 - Project folder structure. Adapted from (AEC (UK), 2015)

There are no spaces in the folder names as this can potentially interfere with certain file management tools and collaboration across the internet (AEC (UK), 2015). The structure will be reviewed by the BIM Manager as part of the BEP development for each project.

7.1.1.4. Data security

A data security protocol should be implemented to prevent data corruption, virus infections, and data misuse. It is recommended to establish a file permission strategy on the shared folder system, where only appropriate organizations in the project have write permissions within their assigned folders, and the remainder of the team has read-only permission. This would prevent data loss or damage during the information exchange and maintenance.

7.1.2. Naming Conventions

All electronic project information should be named following BIMMS Standard Naming Conventions. Applying this standard naming system results in fewer misunderstandings and errors when exchanging data among the stakeholders. It also establishes coherency of project documentation.

The general rules on naming convention are summarized as follows:

Table 37 - General naming convention rules

Rule	Example
Separate fields by a hyphen character “-“or an underscore “_”, and use Title Case, capitalize all words except non-initial articles.	BIMMS-Building A-Plans.pdf
Spaces are accepted to separate words in a field. There is no need to use an underscore ‘_’ for this purpose.	D:\ BIMMS Library\Curtain Wall Panels\
Avoid using special characters in files and folders; Only alphabetic letters A-Z, hyphen, underscore, and numbers 0-9 should be used for all fields.	\ / : * ? “ < >	[ ] & $, . { }@
Filename must be fully descriptive without having to open it and independent of its location.	BIMMS-Awning Window-Curtain Panel.rfa
Do not exceed 260 characters for the folder name and filename character count. Although it is unlikely to exceed the 260 characters count, it may be possible due to complicated directory organization and backups created over backups	C:\Users\ BIMMS \My Documents\ My Project\To Publish\Consultants\Favourite Project\Best Project\BIM Guide\New Manual.doc (114 character)
Use sequential numbering, meaning prefixing leading zeroes to the names	01, 02, A01, A02… instead of 1, 2, A1, A2
Make the version in the file name explicit if the file goes through changes. It can be either the date or the revision.	If a file is initially named: WE435-CD-GF Bedroom 011-VS.png And goes through several revisions, the successive names will be: WE435-CD-GF Bedroom 011-VS-R01.png WE435-CD-GF Bedroom 011-VS-R02.png In case of archiving, place the archive date at the beginning of the file name: 20210411-WE435-CD-GF Bedroom 011-VS.png

7.1.2.1. Folder Naming Convention

Folder names should be indicators as to what the folder contains. The folders shall be named using the following format: YY-MM-DD_Description

Table 38 - Folder naming convention format

Field	Description
YYYY	Four-digit Year
MM	Two-digit Month
DD	Two-digit Day
Description	Brief User Description (up to 24 characters)

Example for Folder naming: 2021-06-18_Sheets

7.1.2.2. File Naming Convention

All electronic files shall be named following the standard File Naming Convention, including Revit files (RVT), Plotsheet files (PDF), Revit Family files (RFA), AutoCAD files (DWG), Rhino files (SAT), Image files (JPG, MOV), Animation files (AVI), Microsoft Office files (DOC, XLS, HTML, TXT), Navisworks files (NWF, NWC, NWD) and Analysis files (multiple formats).

Naming of files shall be based on ISO 19650-2 container naming (Figure 25) fields are optional for a more accessible and straightforward naming convention.

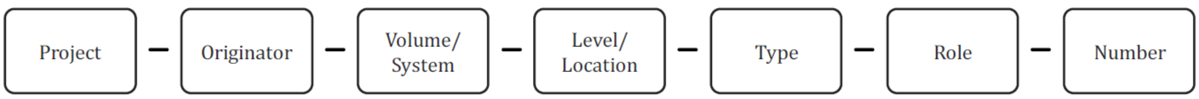


Figure 25 - File naming fields (BSI, 2019b)

The optional "Description" field can be added to make model file naming easier to interpret. Any adjustments should be clearly outlined in the Project BIM Execution Plan to preserve compliance.

Table 39 outlined what each field implies:

Table 39 - File naming convention fields

	Field	Description
1	Project (2 or 6 characters)	An abbreviated code or number identifying the project
2	Originator	Code for organization creating information.
3	Volume/System (2 characters)	A unique identifier should be defined for each volume/system and fixed within the project information standard.
4	Levels and location (2 characters)	Identifier of which level, or group of levels, the model file relates to if the project is sub-divided by levels.
5	Type (2 characters)	Document type, which will be M3 for 3D model files.
6	Role (1 or 2 characters)	1 or 2 character discipline identifier code. Refer to Table 43.
7	Number (Recommended 5 characters)	5 character identifier. It should be noted that as the Name is made up by concatenating all fields. The Number part is only unique where other fields are the same. See examples.
8	Description	Descriptive field to define the type of data portrayed in the file. Avoid repeating information codified in other fields. Can be used to describe any part of the previous fields, or to further clarify any other aspect of the contained data.

Some examples of model file naming are shown below:

Table 40 - Model file naming examples

Model File Name	Description
XYZ-BIMMS-XX-XX-M3-A-00001-Arch_Building_Model	BIMMS Architectural building model – no zones or segregation of floors
XYZ- BIMMS-Z1-XX-M3-ME-00001-Building_Services_Model	BIMMS Zone 1 Building Services model
XYZ- BIMMS-Z6-01-M3-S-00001-Structures_Model_Local	BIMMS Zone 6 Structures model of Level 01. Local version

Follows some examples of drawing file names:

Table 41 - Drawing file naming examples

Drawing File Name	Explanation
XYZ- BIMMS -XX-GF-DR-A-00001 Ground_Floor_GA_Plan; XYZ- BIMMS -XX-01-DR-A-00001 First_Floor_GA_Plan; XYZ- BIMMS -XX-02-DR-A-00001-Second_Floor_GA_Plan	The Number component is the same as the Floor codes change for each Name.
XYZ- BIMMS -XX-XX-DR-A-00001-GA_Elevation_Sheet_1; XYZ- BIMMS -XX-XX-DR-A-00002-GA_Elevation_Sheet_2; XYZ- BIMMS -XX-XX-DR-A-00003-GA_Elevation_Sheet_3	The Number component changes with each example drawing as all other fields are identical.
XYZ- BIMMS -XX-XX-SH-A-00001-Internal_Door_Schedule; XYZ- BIMMS -XX-XX-SH-A-00002 External_Window_Schedule	The Number component changes with each example schedule as all other fields are identical.

Project Code

Each project within the company is assigned a unique project identifier. At the beginning of all projects the Project Identifier or Code should be assigned to support the proper naming of model files, content and other. There are no standard codes for the project field (BSI, 2019b).

Type

Based on the ISO 19650-2, a unique identifier should be defined for each type of information, to identify the type of information held within the information container and fixed within the project information standard. Table 42 lists the standard codes that may apply in a project.

Table 42 – Type codes (BSI, 2019b)

Information	Type Code
Animation file (of a model)	AF
Bill of quantities	BQ
Calculations	CA
Combined model (combined multidiscipline model)	CM
Correspondence	CO
Cost plan	CP
Clash rendition	CR
Database	DB
Drawing rendition	DR
File note	FN
Health and safety	HS
Information exchange file	IE
2D model	M2
3D model	M3
Minutes / action notes	MI
Model rendition for other renditions, e.g. thermal analysis, etc.	MR
Method statement	MS
Presentation	PP
Programme	PR
Room data sheet	RD
Request for information	RI
Report	RP
Schedule of accommodation	SA
Schedule	SH
snagging list	SN
specification	SP
survey	SU
visualization	VS

Discipline and Roles Codes

The discipline code must be prefixed to all model files, content, and support files. Discipline codes recommended to use by the BIMMS are represented in the table below.

Table 43 - Discipline codes (BSI, 2019b)

Discipline Name	Designator Code
Architect	A
Building Surveyor	B
Civil Engineer	C
Electrical Engineer	E
Facilities Manager	F
Geographical and Land Surveyor	G
Heating & Ventilation Designer	H
Interior Designer	I
Client	K
Landscape Architect	L
Mechanical Engineer	M
Public Health Engineer	P
Quantity Surveyor	Q
Structural Engineer	S
Town and County Planner	T
Contractor	W
Sub-Contractor	X
General	Z

7.1.2.3. Material Naming Convention

Naming the materials should begin with the Finish Material followed by the Manufacturer Name, the Finish Code, and an optional User Description.

The filename should take the form of: <Finish>-<Manufacturer>-<Code>-<Description>

Table 44 - Material naming fields

Field	Description
Finish	Finish Material
Manufacturer	Manufacturer Name or Generic Primary Characteristic or Shape
Finish Code	Finish Code or Model Number
User Description (Optional)	Brief description (up to 24 characters)

Example for Material naming: Paint-Sherwin Williams-SW6034-Arresting Auburn

7.1.2.4. Family Naming Convention

Family Names

Family files shall be named beginning with the Revit Object Category followed by the Manufacturer of the product or the word “Generic”, and ending with a Description and/or a Model Number.

The filename should take the form of: <Category>-<Manufacturer>-< Description and/or Model Number>.rfa

Table 45 - Family naming fields

Field	Description
Category	Names the element that the family creates
Manufacturer	Manufacturer Name or the word “Generic”. Underscores (_) may be used in place of dashes (-) for multi-segment Manufacturer names.
Description and/or Model Number	A brief Description and/or a Model Number. Underscores (_) may be used in place of dashes (-) for multi-segment Descriptions or if a Model Number is included with a Description.

Examples for Family names:

Structural Framing-Generic-Steel Girder.rfa

Electrical Equipment-Square D-Distribution Panelboard.rfa

Family Types

The key distinctions or variations between the various Family options are indicated by types within a Family file. The Type names shall take one of the following forms, depending on the Family Component:

- <Model> or <Series Number>
- <Value> or <Capacity>
- <Height>x<Width>x<Depth>

Examples for Family names with types:

- Structural Framing-Generic-Steel Girder.rfa

• W6x10

• W6x12

- Electrical Equipment-Square D-Distribution Panelboard.rfa

• 208V MCB - Surface

• 480V MLO – Surface

7.1.2.5. View Naming Convention

Within the Project Browser, views are named using the View Type Code first, then an optional Level/Sequence Number, and finally an optional User Description.

<View>_<Level/Sequence>_<Description>

Table 46 - View naming fields

Field	Description
View	View Type Code. Refer to Table 47
Level/Sequence (Optional*)	Level Number or Sequence Number (Two-digit integer)
Description (Optional*)	Brief User Description (up to 24 characters)

*A Level/Sequence number, a Description, or both must be included in all View names.

Example for View naming: First Floor Plan View, “FP_01”

The following table presents the view type code for all disciplines.

Table 47 - view type codes

VIEW TYPE CODE	VIEW TYPE NAME
3D	3D Views
AP	Area Plans
BS	Building Sections
CP	Ceiling Plans
CS	Construction Staging or Construction Sequence
DL	Drawing List
DR	Drafting Views
DS	Detail Sections
DV	Detail Views
EE	Exterior Elevations
EP	Enlarged Plan
ES	Engineering Estimates
FE	Framing Elevation
FP	Floor Plans
I IE	Interior Elevations
KL	Keynote Legend
LG	Legends
LP	Location Plan
MT	Material Takeoff
NB	Note Block
NO	General Notes
ON	One Line Diagram Plan
QP	Equipment Plan
RD	Riser Diagram
RO	Roof Plan
RP	Reports
SC	Sections
SL	Sheet List
SP	Site Plan
SQ	Schedule/Quantities
VL	View List
WT	Walkthroughs
X	Other

Example for Architectural Floor Plans:

FP-01-FIRST FLOOR

FP-02-SECOND FLOOR

FP-03-THIRD FLOOR

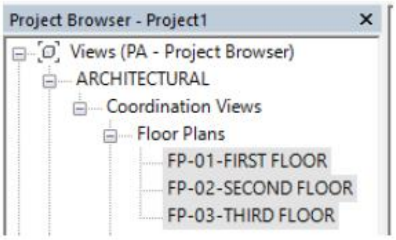


Figure 26 - Example of Project Browser showing the floor plans

7.1.3. Presentation Styles[16]

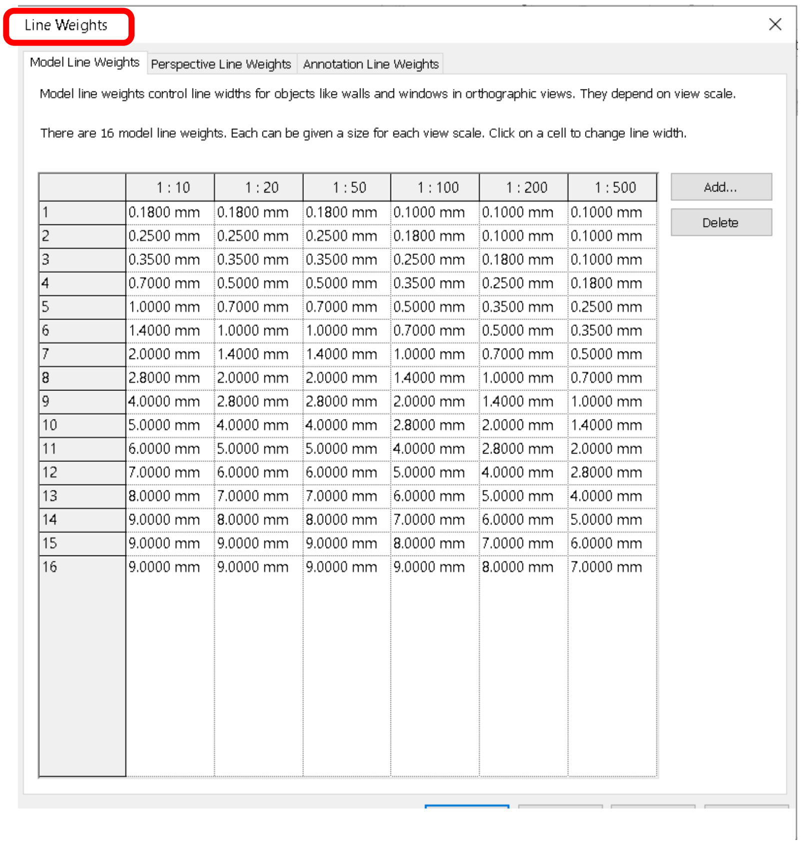
This section presents the criteria which ensure the appearance of drawing output from BIM is consistent and of the highest quality.

7.1.3.1. Line Weights

The graphical display of on-screen data, as well as all published output, is controlled by line weights. Model elements have scale-dependent line weights, whereas Annotation objects have fixed line weights. The plotted look of modelled components must be represented in a way that gives the drawing ‘depth' and allows for proper differentiation of elements cut in section, profile view and priority elements (CIC, 2020).

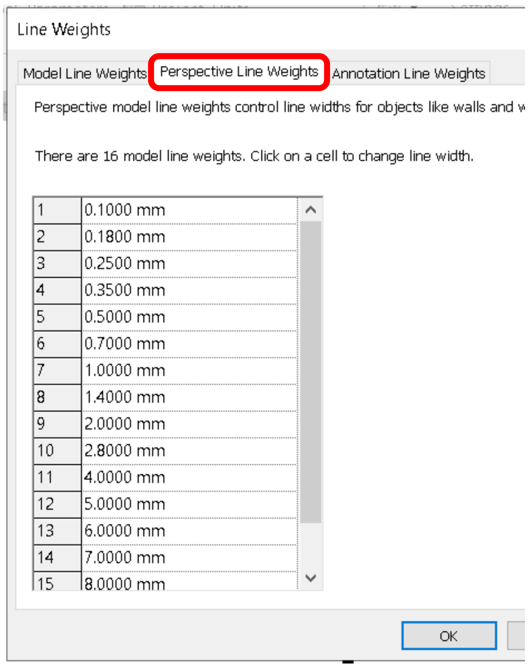
[16] Based on the recommendation provided by ISO/TS 12911(2012), BIM guidance documents may provide the presentational conventions for application in the generation of drawings and documents.

Refer to software-specific guidelines for Line Weights. In Revit, 16 Line Weights have been provided for Model, Perspective and Annotation Objects. Across the range of drawing scales, each can be given a plotted thickness.



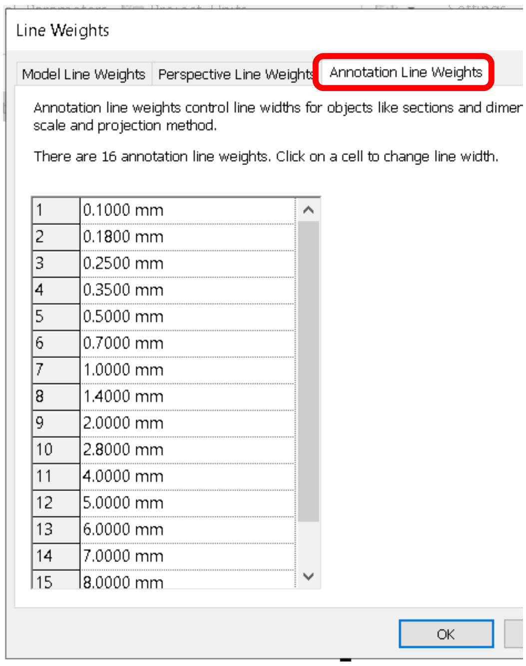
	1 : 10	1 : 20	1 : 50	1 : 100	1 : 200	1 : 500
1	0.1800 mm	0.1800 mm	0.1800 mm	0.1000 mm	0.1000 mm	0.1000 mm
2	0.2500 mm	0.2500 mm	0.2500 mm	0.1800 mm	0.1000 mm	0.1000 mm
3	0.3500 mm	0.3500 mm	0.3500 mm	0.2500 mm	0.1800 mm	0.1000 mm
4	0.7000 mm	0.5000 mm	0.5000 mm	0.3500 mm	0.2500 mm	0.1800 mm
5	1.0000 mm	0.7000 mm	0.7000 mm	0.5000 mm	0.3500 mm	0.2500 mm
6	1.4000 mm	1.0000 mm	1.0000 mm	0.7000 mm	0.5000 mm	0.3500 mm
7	2.0000 mm	1.4000 mm	1.4000 mm	1.0000 mm	0.7000 mm	0.5000 mm
8	2.8000 mm	2.0000 mm	2.0000 mm	1.4000 mm	1.0000 mm	0.7000 mm
9	4.0000 mm	2.8000 mm	2.8000 mm	2.0000 mm	1.4000 mm	1.0000 mm
10	5.0000 mm	4.0000 mm	4.0000 mm	2.8000 mm	2.0000 mm	1.4000 mm
11	6.0000 mm	5.0000 mm	5.0000 mm	4.0000 mm	2.8000 mm	2.0000 mm
12	7.0000 mm	6.0000 mm	6.0000 mm	5.0000 mm	4.0000 mm	2.8000 mm
13	8.0000 mm	7.0000 mm	7.0000 mm	6.0000 mm	5.0000 mm	4.0000 mm
14	9.0000 mm	8.0000 mm	8.0000 mm	7.0000 mm	6.0000 mm	5.0000 mm
15	9.0000 mm	9.0000 mm	9.0000 mm	8.0000 mm	7.0000 mm	6.0000 mm
16	9.0000 mm	9.0000 mm	9.0000 mm	9.0000 mm	8.0000 mm	7.0000 mm

Figure 27 – Model line weights



1	0.1000 mm
2	0.1800 mm
3	0.2500 mm
4	0.3500 mm
5	0.5000 mm
6	0.7000 mm
7	1.0000 mm
8	1.4000 mm
9	2.0000 mm
10	2.8000 mm
11	4.0000 mm
12	5.0000 mm
13	6.0000 mm
14	7.0000 mm
15	8.0000 mm

Figure 28 – Perspective line weights



1	0.1000 mm
2	0.1800 mm
3	0.2500 mm
4	0.3500 mm
5	0.5000 mm
6	0.7000 mm
7	1.0000 mm
8	1.4000 mm
9	2.0000 mm
10	2.8000 mm
11	4.0000 mm
12	5.0000 mm
13	6.0000 mm
14	7.0000 mm
15	8.0000 mm

Figure 29 – Annotation line weights

7.1.3.2. Line Pattern

Refer to software-specific guidelines for Line Patterns. There are a number of predefined line pattern in Revit as it is shown in Figure 30. Additional line patterns can be created and added to the project.

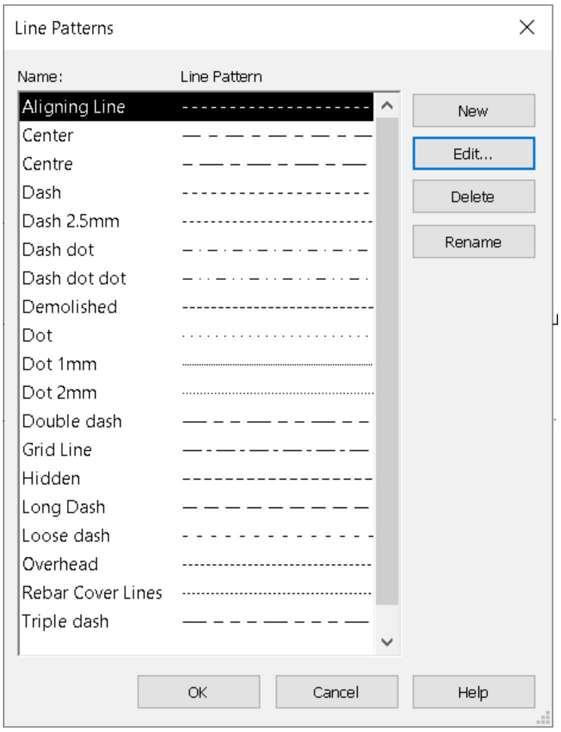
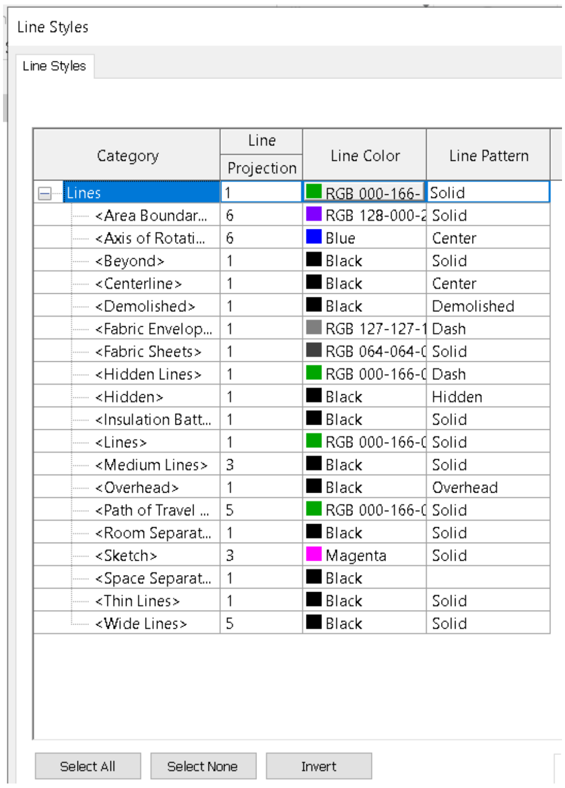


Figure 30 - Line patterns

7.1.3.3. Line Styles

Refer to software-specific guidelines for Line Styles. There are a number of predefined line styles in Revit as it is shown in Figure 31. Additional line styles can be created and added to the project.



Category	Line Projection	Line Color	Line Pattern
Lines	1	RGB 000-166-	Solid
<Area Boundar...	6	RGB 128-000-2	Solid
<Axis of Rotati...	6	Blue	Center
<Beyond>	1	Black	Solid
<Centerline>	1	Black	Center
<Demolished>	1	Black	Demolished
<Fabric Envelop...	1	RGB 127-127-1	Dash
<Fabric Sheets>	1	RGB 064-064-0	Solid
<Hidden Lines>	1	RGB 000-166-0	Dash
<Hidden>	1	Black	Hidden
<Insulation Batt...	1	Black	Solid
<Lines>	1	RGB 000-166-0	Solid
<Medium Lines>	3	Black	Solid
<Overhead>	1	Black	Overhead
<Path of Travel ...	5	RGB 000-166-0	Solid
<Room Separat...	1	Black	Solid
<Sketch>	3	Magenta	Solid
<Space Separat...	1	Black	
<Thin Lines>	1	Black	Solid
<Wide Lines>	5	Black	Solid

Figure 31 - Line styles

7.1.3.4. Fill Patterns

Refer to software-specific guidelines for Fill Patterns. A number of default Fill Patterns for Model and Draughting is predefined in the Revit and alternative Fill Patterns shall be created and added to the project. Instead of being assigned as 2D patches, hatch patterns should be applied to the relevant materials for the elements whenever possible (Figure 32 and Figure 33).

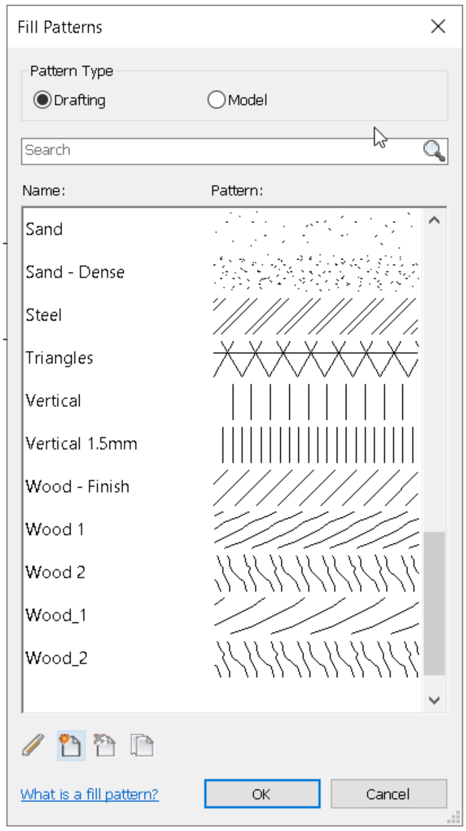


Figure 32 – Fill patterns for Drafting

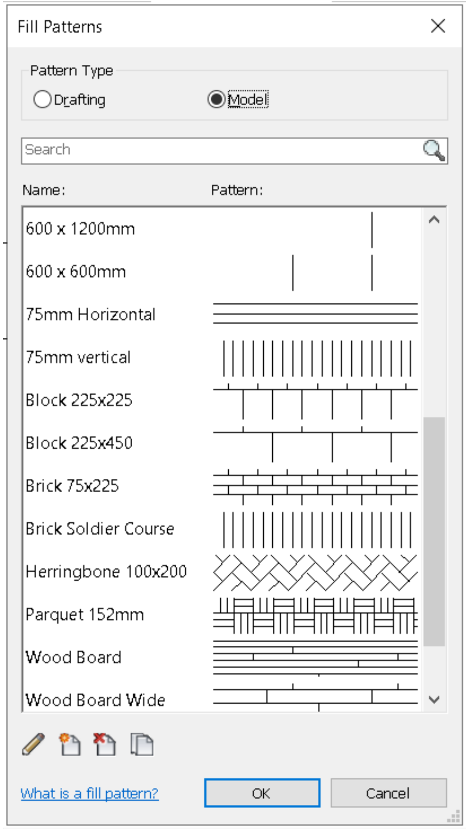


Figure 33 – Fill patterns for Model

7.1.3.5. Text Assignment

The Text Style shall be **ARIAL NARROW** if no pre-defined text standards exist. The appearance of the text shall be consistent across a set of drawings. All text shall be restricted to the following sizes (AEC (UK), 2012-b); alternative text sizes shall be used with documentation in the BEP.

Table 48 – Text assignment recommendation

Text height (mm) Plotted full size	Line Weight Allocation	Usage
1.8	2	General text, dimensions, notes – used on A3 & A4 size drawings
2.5	3	General text, Dimensions notes
3.5	4	Sub-headings
3.5	5	General text, dimensions, notes- A0 drawings
5.0	7	Normal titles, drawing numbers
7.0	8	Major titles

7.1.3.6. Paper Size

The recommendation of this Guide for paper sizes is ISO Sizes Drawings. If custom sizes are needed, it must be agreed and documented. ISO 216:2007 specifies the paper dimensions for the “A” paper series. A0, A1, A2, A3, A4, and A5 are the most prevalent paper sizes. The table below shows the dimension of the most common “A” series paper sizes used in Engineering Drawings.

Table 49 – A series paper sizes

Paper Size	Dimensions (cm)	Paper Area (m2)
A5	14.8 x 21	0.03125
A4	21 x 29.7	0.0625
A3	29.7 x 42	0.125
A2	42 x 59.4	0.25
A1	59.4 x 84.1	0.5
A0	84.1 x 118.9	1

The paper sizes for architectural, structural and MEP drawing should be A1, A2 or A3. A4 paper size is too small and A0 paper size is too big. A0 is typically used for very large Site Plans or Overall Plot Plans. A4 should only be used for small details on the construction site and when fax transmission is required. All drawings must be in a landscape mode. Graphics or text in the drawing should not overlap or extend beyond the drawing boundary.

7.1.3.7. Scales

The choice of scale should be carefully considered. Factors affecting choice are as follows:
• Communication of the information for the work to be carried out.
• Economy of effort and time in preparation
• Maintaining the standard sheet size
The minimum scales for shop drawings shall be as follows.
• General Arrangement Drawings 1:1000, 1:500, 1:200
• Details 1:50, 1:20, 1:10 (Rail Baltica, 2018).

7.1.3.8. Annotations

- Uniformity, clarity, and readability are significant for the use of annotations in the models.
- Where possible the annotation shall read in the same direction as the drawing or intended output, typically horizontally or vertically, unless placed, for example, along an element to indicate chainage.
- Where possible annotation shall not be obscured or cut by the drawing content useable area and where drawings are tiled adequate space provided for complete annotation within the continuation area.
- The space at the base of the title block shall be used for general notes, legends and any other criteria or special instructions. Where space is limited, these notes may be placed in the drawing content useable area but shall be clearly distinguished from the drawing content and any other annotation, labelled appropriately, and inserted with a background (Rail Baltica, 2018).

7.1.3.9. Dimensioning

Dimensions shall be lettered parallel to and above the dimension line and shall be shown to identifiable, finite points, or lines (Figure 34).
No dimension value must be edited manually; any change that includes a dimension change must ensure that the relative feature is changed, not just the dimension element.

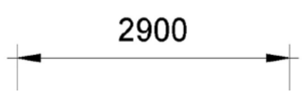


Figure 34 - Dimension symbol

7.2. Software

7.2.1. Software and File Format

7.2.1.1. Software Products

BIMMS currently utilises Autodesk products as its standard BIM software. However, for each project, the BEP determines what software and tools shall be used for that specific project. The most used Autodesk products are listed in Table 50 below.

Table 50 - Autodesk BIM software

Software	Use
Autodesk Revit	Design, Construction development and update Models for all trades. Models are used for drawings development, trades coordination, construction phasing, quantity take-off, scheduling.
Autodesk Civil 3D	Develop surfaces, profiles, alignments, corridors, pipe networks and quantity take-offs
Autodesk Navisworks	Interference/clash Detection, 4D and 5D simulation. site Planning and logistics. program wide review.
BIM Collaborate Pro	Cloud-based coordination and collaboration software
Autodesk Recap	LiDAR Point cloud view and manipulation
Autodesk Design Review	View, mark up, and print 2D and 3D files
Autodesk InfraWorks	Geospatial platform for infrastructure

Other software require approval by the BIM Manager and the application use must be documented in the BEP. Other software might include:

Table 51 - Other BIM software

Use	Software
BIM authoring	ArchiCAD, Bentley BIM, Trimble Tekla Structures, SketchUp, Allplan, Vico Office
BIM coordination	Solibri Model Checker
Space Programming	Affinity, Beck Technologies
Energy Modelling	Green Building Studio (GBStudio), Ecotect, EnergyPlus

7.2.1.2. Versioning

Based on the non-backwards compatibility of the Revit-based applications, versioning of the software is significant and should be managed throughout the project lifecycle. The version number of any software to be used must be announced at the beginning of the project and documented in the BEP. The identified versioning must be maintained throughout the project close-out unless the team agrees to upgrade to a newer version which may happen in the long-period projects. The versioning update in big projects with multiple number of models require great deal of quality checking to assure no information is lost in the process.

7.2.1.3. File Format

Document formats will depend on the type of document being delivered which is defined in the BEP. For every model submission, the model in proprietary format and open format will be delivered.

Examples for the BIM native format are RVT (Autodesk Revit) or PLN & PLA (ArchiCAD).

For the BIM Open Format, IFC format preferably IFC4 (the latest version) is used. In case the authoring software is not compliant, IFC 2x3 could be utilized.

7.2.1.4. Data Exchange Formats and Interoperability

7.2.1.4.1. IFC

BuildingSMART International developed Industry Foundation Classes (IFC) and defines it as "*a standardized, digital description of the built environment, including buildings and civil infrastructure. It is an open, international standard, meant to be vendor-neutral, or agnostic, and usable across a wide range of hardware devices, software platforms, and interfaces for many different use cases*" (BuildingSMART, 2021b).

IFC is typically used to exchange information from one party to another for a specific business transaction. For example, an architect may provide an owner with a model of a new facility design, an owner may send that building model to a contractor for a bid, and a contractor may supply the owner an as-built model with details describing installed equipment and manufacturer information. IFC can also be used as a means of archiving project information, whether incrementally during the design, procurement, and construction phases, or as an "as-built" collection of information for long-term preservation and operations purposes (BuildingSMART, 2021b).

IFC can be considered as the best format for data exchange in AEC since:

- Most of software pieces in the industry can export proprietary files into IFC format and this results in greater interoperability among various disciplines.
- It is an open non-proprietary format that is free to use for everyone.
- It is a non-editable format that secures the intellectual property of the creator.
- In contrary to proprietary formats such as Revit, subsequent versions of IFCs are backwards-compatible.

The quality of the IFC creation is responsibility of the appointed party BIM Management team, and the quality of the IFC created will be one of the model quality checks.

IFC Export

Despite all advantages of IFC, the export to IFC format is still challenging. This is because the exported IFC must have adequate amount of data -not too much and not too little- to be applicable.

It may be filtered out certain redundant parameters from the IFC schema to make an export with the appropriate amount of data. With this export, Model View Definition (MVD) is created (Figure 35).

In general, a MVD, is a selection of entities of the overall IFC schema to facilitate a specific use or workflow. MVDs can be as broad as nearly the entire schema (for example for archiving a project) or as specific as a couple object types and associated data (for example for pricing a curtain wall system) (buildingSMART, 2021c).

For example, if an architect needs to export the model for energy analysis, instead of exporting the entire model and imbedded data, the predefined IFC export called “energy analysis MVD” is utilized to export only relevant information.

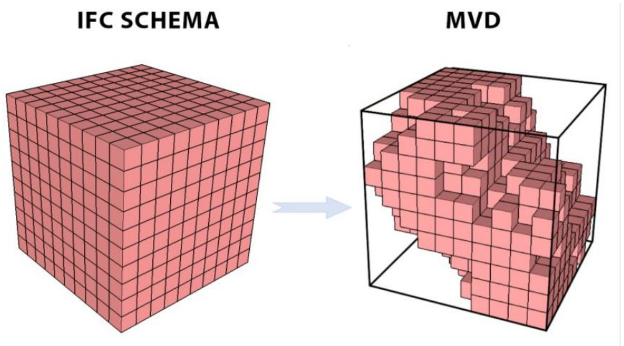


Figure 35- IFC and MVD (BibLus, 2021)

The IFC schema has different versions and is constantly evolving. IFC 4 is the most recent version, released in 2013 (previous versions were labelled as 1.0, 1.5, 1.51 and subsequently 2x, 222, 23).

IFC files may be exported and exchanged between software products using IFC, IFCXML and IFCZIP file formats (Figure 36).

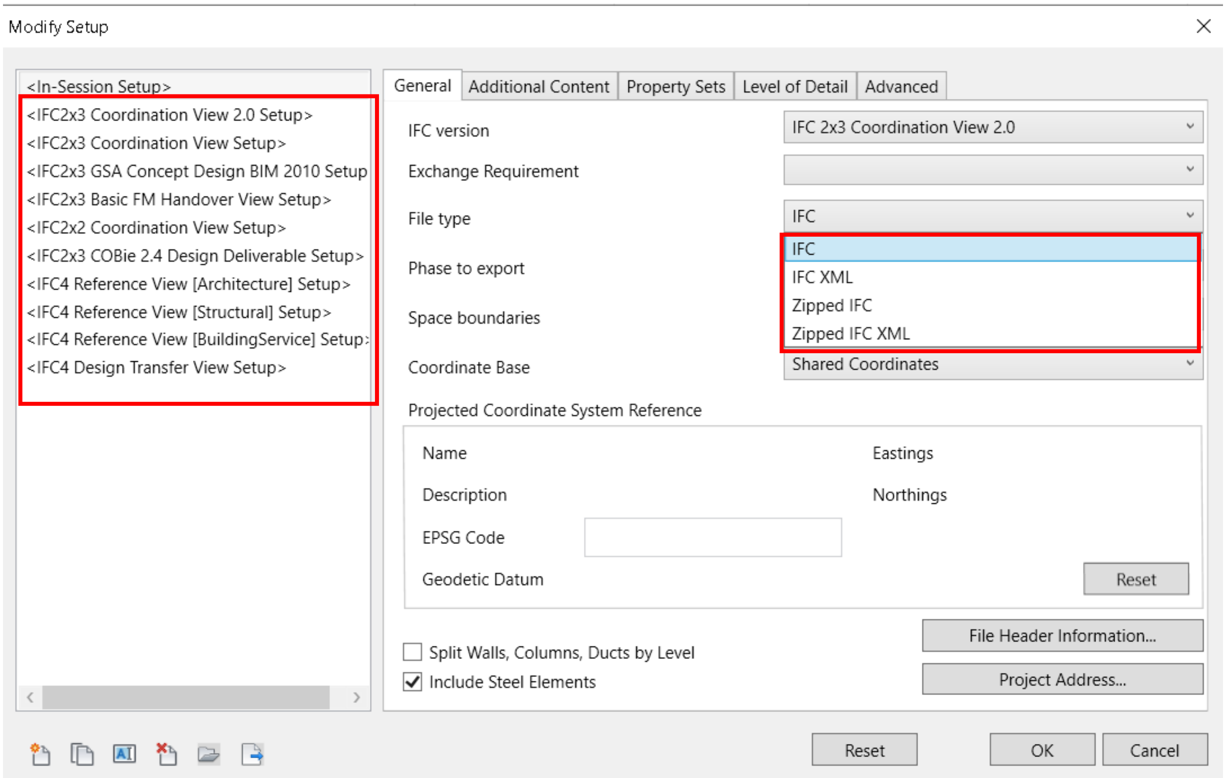


Figure 36 - Export to IFC in Revit, IFC versions on the left and IFC types on the right

Table 52 - IFC types and their differences. (BIM Corner, 2020)

IFC Types	Differences between types of IFC model exports
	This is the default exchange format represented by a plain ASCII text file (only text, without formatting). The scheme defines how the text of the file is transformed into objects connected by mutual relations.
	IFC data file is using XML document structure instead of ASCII like it was in the standard .ifc file. The .ifcXML file is usually 300-400% larger than the .ifc file.
	It is a standardized .ifc or .ifcXML compression format (using appropriate compression algorithms). This is possible because both .ifc and .ifcXML are saved as text files. .IfcZIP files usually compress the .ifc file by 60-80% and the .ifcXML file by 90-95%.

Purposes for IFC Export

Depending on the stage of the project, IFC export serves a variety of purposes. Table 53 outlines the purposes for the IFC export and why it is important.

Table 53 - IFC export purposes (BIM Corner, 2021)

Purposes for IFC Export	Description	Importance
Reference model	To allow next designers to refer to previous model	Referring the model ensures that designer is basing on the correct basis
Multidisciplinary coordination	To conduct clash detection and quality assurance	Dramatically reduces clashes on site and provides a good base for contractors
Quantity surveying	Take-off model for project tendering or for ordering materials on site	Facilitate the correct take-off that results in less change orders and risky pricing
Model-based construction	Using model on the construction site to build what has been designed	IFC models are the only source of information for contractors
Facility Management	Handover of as-built documentation to manage facility during its lifecycle	Prevent data loss that happens in transition to operational phase

7.2.1.4.2. Cobie (Construction Operation Building information exchange)[17]

Cobie is a standard of documentation containing data to manage an object in the form of a spreadsheet. It allows for:

[17] The Cobie topic is discussed in 6.2.3 section to familiarise readers with the concept. However, the Cobie topic was a controversial topic during the meetings with BIMMS and the comments received from the survey. Some opine that Cobie is not an important part of the BIM process and It is not necessary to provide instruction in this Guide for the Cobie. Thus, it was decided to not to include more in detail instruction about it in this section.

- Interoperability at the user level – the data recorded in the standard are accessible and understandable to practically any supplier and other participants of the investment process. The data collected in accordance with the COBie can be easily imported into FM class systems.
- Interoperability at the designer level – majority of the programs used to create 3D models include the option of automatic generation of the COBie file. See section 6.2.3 Construction Operations Building Information Exchange (COBie) for more information on Cobie.

7.2.2. BIM Object

7.2.2.1. Definition of BIM Objects

The digital building blocks that are used to generate virtual assets must be standardized in order for users from different companies, disciplines, or geographical areas to efficiently utilise model information. These building blocks are commonly known as BIM objects (NBS, 2019).

A BIM object is made up of several components:

- Information content that defines the product.
- Model geometry representing the product's physical characteristics.
- Behavioural data such as detection, maintenance and clearance zones that enable the BIM object to be positioned in (or function in the same manner as) the product itself (NBS, 2019).

7.2.2.2. Types of Objects

Objects can be classified in two different methods that are outlined in Table 54 and Table 55.

Table 54 - BIM object types (NBS, 2017)

BIM Object	Specification
component	building products that have fixed geometrical shapes such as windows, doors, boilers etc.
Layered	building products that do not have a fixed shape or size such as carpets, roofing, walls, and ceilings.

Table 55 - BIM object types. Adapted from (MPA, 2015)

BIM Object	Specification
Generic Objects	BIM applications include generic representations of building products, assembled elements, and components of building systems.
Manufacturer's Model Product Objects and Elements	Objects and elements acquired from manufacturers often have more information or geometric detail than is necessary to keep in the BIM. The object should retain its overall dimensions and critical components. Embedded performance data shall be retained for analysis and specification purposes.
Custom Created Model Elements	Teams may create BIM objects and elements utilizing the appropriate BIM authoring tool templates and procedures. These must be assigned to the correct category, family, type, and/or sub-type (Figure 37) according to the authoring software's best practices, and they must carry the required and desired attribute data consistent with BEP standards. Objects generated in the development of a project will be stored in the WIP area of the project folder structure.

7.2.2.3. Family / Component Content Libraries

To ensure the consistency, each discipline/package within a project will create and maintain a Family / Component content library that will be utilised by all the members of that discipline within that package.

Different authoring tools refer to the BIM Content according to their technological structure. Table 56 presents a list of the different terminologies:

Table 56 - Examples of BIM objects terminology per software

BIM Software	Content name
Revit	family
ArchiCAD	components
Rail Track / Open Roads	features & components
AECOsim	family part
Civil 3D	Assembly / subassembly & blocks
Allplan	components
Tekla Structures	components

7.2.2.4. Hierarchy of Revit Objects

All families, including generic families, must be assigned to appropriate categories and subcategories. When a family is created, it is assigned a category. The category defines its top level of identification (for example, Door, Window, or Casework) within the project environment. When a family is utilized in a project, it can be found in the Project Browser under its category, and elements created by family types are scheduled according to that category. In Revit software, categories are predetermined and cannot be created or changed by the user. Some families have established subcategories, but more subcategories can be added as needed (Bimstore, 2020).

Every object in Revit is an element and Figure 37 shows how and Revit classifies elements by categories, families, types, and instances.

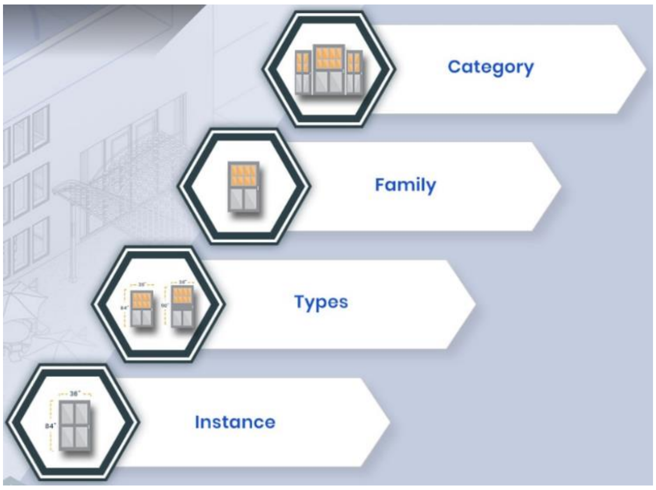


Figure 37 - Hierarchy of Revit objects (Bwail, 2019)

Category

A category is a broad group of elements that it is used to model or document a building design.

Example:

- Categories of model elements: walls, beams.

Family

Families are classes of elements in a category. A family is a group of elements with a common set of parameters (properties), identical use, and similar graphical representation. Different elements in a family may have different values for some or all properties, but the set of properties—their names and meaning—is the same.

Example:

- Single-flush doors could be considered one family, although the doors that compose the family come in different sizes and materials.

Revit uses the three following kinds of families:

Table 57 - Three kinds of families in Revit (Autodesk, 2014)

Revit Families	Specification
Loadable families	Loadable families can be loaded into a project and created from family templates. You can determine the family's set of properties as well as its graphical representation.
System families	System families are not available for loading or creating as separate files. The set of properties and the graphical representation of system families are predefined in Revit.
In-place families	In-place families define custom elements that you create in the context of a project. When your project requires unique geometry that will not be reused or geometry that must preserve one or more relationships with other project geometry, create an in-place element.

Type

A family type is a specific representation in a family defined by distinct parametric. Graphical and documentation characteristics, unique from other family types. For example, within the single-flush door family, there can be several types of single doors such as 90 * 210 full vision and 84 * 210 vision panel.

Instance

The actual items (individual elements) that are inserted in the project and have defined places in the building (model instances) or on a drawing sheet are referred to as instances (annotation instances). Without modifying family type parameters, instance parameters can be changed.

Instances are the actual items (individual elements) that are inserted in the project and have defined places in the building (model instances) or on a drawing sheet (annotation instances). Instance parameters can be modified without changing family type parameters.

7.2.2.5. Object Category

Any BIM object shall be assigned with the most appropriate and representative category based on its platform system, for example a door BIM object shall be assigned to the “Door” category.

The BIM object may also be assigned with a category based on a classification system. The International Standard ISO 19650 requires a classification system that aligns to the ISO 12006-2 framework. Uniclass 2015 is the leading worldwide example of a classification system based on this framework so that Uniclass 2015 is the recommended classification system for BIM objects in this guide.

The BIM object must be assigned the proper Industrial Foundation Classes (IFC) parameters to simplify the exchange of BIM objects and related information.

7.2.2.6. BIM Object Creation

Determining Design Intent

The extent to which a Revit family is developed is determined by the family's intended application in a project setting. The larger the file size, the slower the performance, loading, and regeneration time of the family will be (BimObject, 2018).

Determining the Template to Use

Use the Revit template that is appropriate for the object that is being developing, such as Revit Architecture for a Door family and Revit MEP for an Air Handling Unit. If the content crosses disciplines, for example, a lighting fixture or plumbing fixture, use the template that has the most requirements, in this case Revit MEP.

Start with a host-based template for objects that are generally hosted by other components, such as a window or light fixture.

A Face-Based or Un-Hosted template should be used for all families, there are some exceptions. For example, for a window or door, use a wall-based template, such as Window.rft or Door.rft. How the family is hosted (or what it does or does not attach to) determines which template should be used to create the family. In general, the choice of a template is driven by the host of the object, with the following exceptions:

Floor-based objects typically use a level-based template unless they are required to cut the floor. For example, Furniture objects are created with a level-based template (BimObject, 2018).

Steps to create an object

The workflow for model content creation can be found below to ensure that your object is created in the most efficient and least error-prone manner (BimObject, 2018).

1. Create a new family file (.rfa) with the suitable family template.

2. Define subcategories for the family to help control the visibility of the family geometry.

3. Create the family skeleton, or framework:
- Define the origin (the insertion point) of the family.
- Lay out and name reference planes to snap to when component geometry is sketched.
- Add dimensions to specify parametric relationships.
- Label dimensions to create type or instance parameters or 2D representation.
- Test, or flex, the skeleton.

4. Specify different parameters to define different family type variations.

5. In solids and voids, add a single level of geometry and confine the geometry to reference planes.

6. Flex the new model (types and hosts) to ensure proper component behaviour.

7. Complete the family geometry by repeating the previous steps.

8. With subcategory and entity visibility options, specify 2D and 3D geometry display features.

9. Save the family, and then test it.

10. For large families that include many types, create a type catalogue.

The steps for family creation can be summarised in the following workflow:

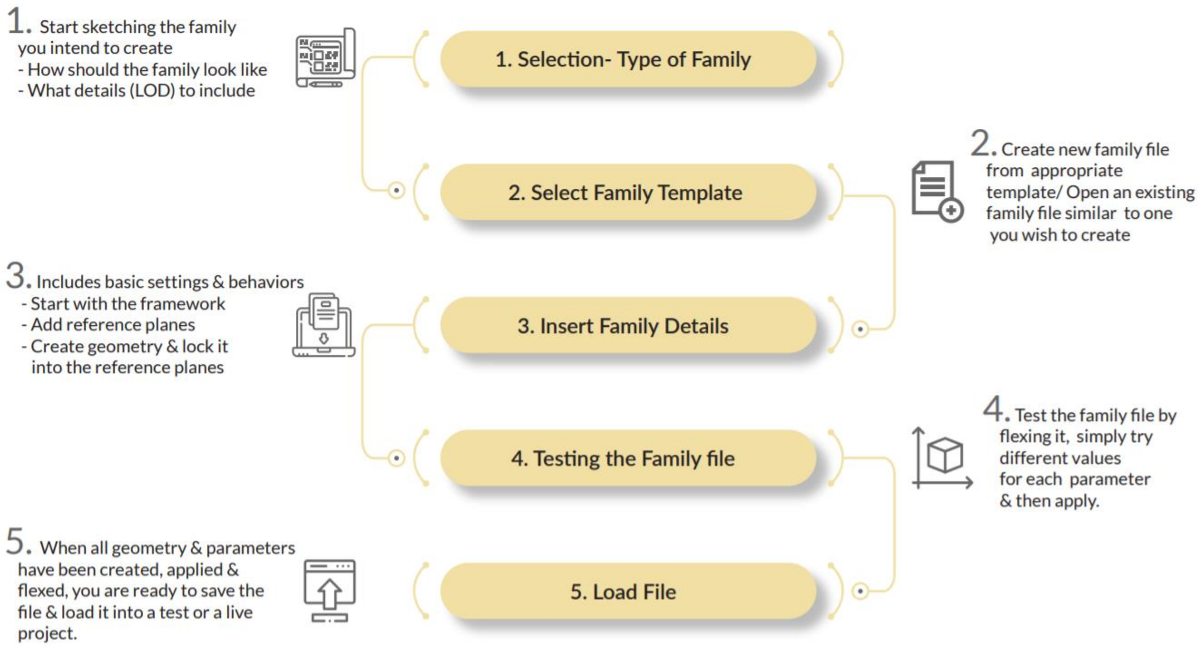


Figure 38 – Family creation workflow (United BIM, 2021)

7.2.2.7. Family Size

To have a Building Information Model with high performance, it is recommended to keep the components' file size as small as possible.

Use the file sizes below as a recommendation for family file size.

Table 58 - Family size recommendation (Bimobject, 2018)

Application	Complexity Level	File Size
Revit Architecture	Simple	300-400 K
	Complex	500 K
Revit MEP	Simple	300-400 K
	Complex	800-1000 K
Revit Structure	Simple	180-200 K
	Complex	300 K

To keep your family as small as feasible, it is suggested the following:

• Purge and check your family before uploading. To delete items that are no longer in use, go to File → Purge Unused (be careful not to remove any material types that may have been added).

• Keep nesting to a minimum and ensure the nested objects are also purged and audited, including removing any unused types.

• Limit the use of custom materials and bitmaps whenever possible.

• Only model what is required to an appropriate level of detail.

• Remove any CAD or images used while building your component and purge to make sure they have been removed.

• Never explode CAD into your family.

• Useful Tip: After building, try doing a 'save as' and save the family with a different name to the one used during creation. This clears out any temporary history data and can cut file sizes by up to 50% (Select compact File option when saving the file) (Bimstore, 2020).

7.2.2.8. Level of Detail

Which components of family geometry appear in different sorts of project views is determined by detail levels. When a Revit element is generated with a family and added to a project view, the appropriate family geometry is displayed based on the view's current detail level (fine, medium, or coarse).

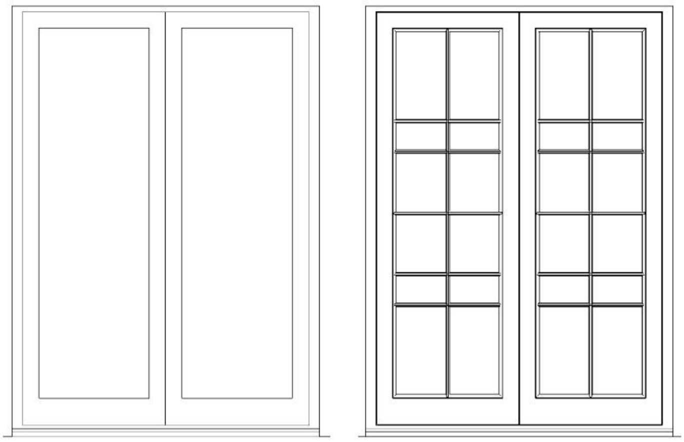


Figure 39 - A door displayed in both Coarse (left) and Fine (right) detail

Recommendations for the level of detail

- Do not model geometry that will not be visible when the family is added to a building model. For example, model simply the face of a table family that includes a drawer, not the complete drawer and its contents.
- Do not duplicate geometry that can be used for different detail levels.
- Depending on the type of family, use the following guidelines when modelling geometry:

Table 59 - Recommendation for the object level of detail (Bimstore, 2020)

If the geometry is...	Set the detail level to...
Smaller than 25 mm	Fine
25 mm – 75 mm	Medium
Larger than 50 mm	Coarse

7.2.2.9. Nesting Families

The term "nested family" refers to a family that has been loaded into another family. It may be more practical to represent sections of the nested family independently from the main family model in some circumstances. Create a door handle ironmongery family, for example, then load it into the door family. This allows to build upon previous work while creating families suited to your needs (Bimstore, 2020).

Nesting family recommendations:

- Instead of nesting, consider creating all the necessary geometry in the family. To fix geometry in place, use reference lines and labels.
- Limit nesting to two levels - The deeper that families are nested, the longer they take to update in the project file.
- Only nest high-value content that may be used in several different families, such as a door handle.
- Be careful when changing a nested component that is shared by more than one family. The component will update all the families in the project file that share the same nested family when it is reload into the project file. Unticking the "shared" button in the "category and parameters" dialogues will cease this behaviour.
- No more than six nested families should be nested into a single family (Bimstore, 2020).

7.2.2.10. BIM Objects' Information (Data Management)

Each object is codified by a set of attributes to qualify it. The Attributes or parameters are the pieces of information linked to each BIM object to describe one specific characteristic of it. This information is very diverse and can define or describe the object or refer to a requirement or classification system for various purposes, such as Geometry, Identification data, Analytical data, Construction Phases, Environmental specifications, Financial estimate, or Exploitation data. Details can also refer to the presence or absence of sub-components like doorknobs, closers, and kickplates. All this information is not included in the BIM object from the very beginning of the project, thus, some fields will be completed in the following phases of the project. This is defined for every phase by the Level of Information (Rail Baltica, 2019, USACE, 2019).

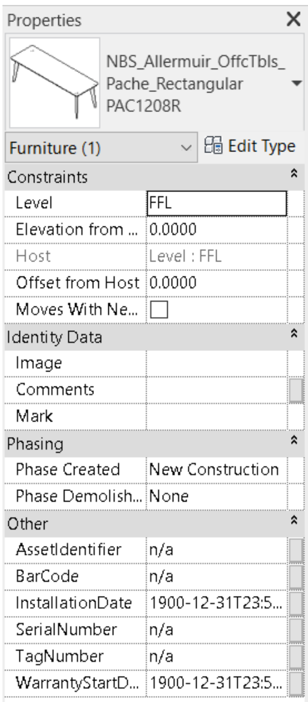


Figure 40 - Example of object parameters

7.2.2.11. Parameter Usage

Families have parameters that not only define the family geometry but identify or classify the elements that are created by the family. All families have predefined parameters that one´s assign values or data to, but it might be added parameters that are not predefined in Revit software (Bimobject, 2018).

Add parameters using “Mange” tab ► “Project Parameter”

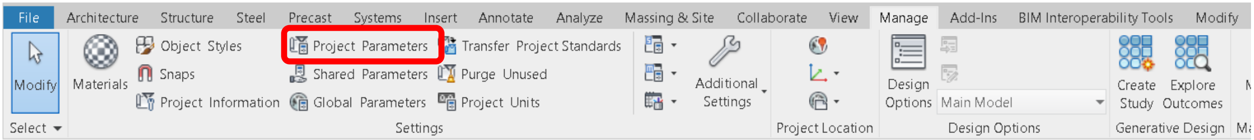


Figure 41 - Adding parameter to the object

In the Parameter Properties dialog, choose the element related category from the right and fill the Parameter Data fields on the left.

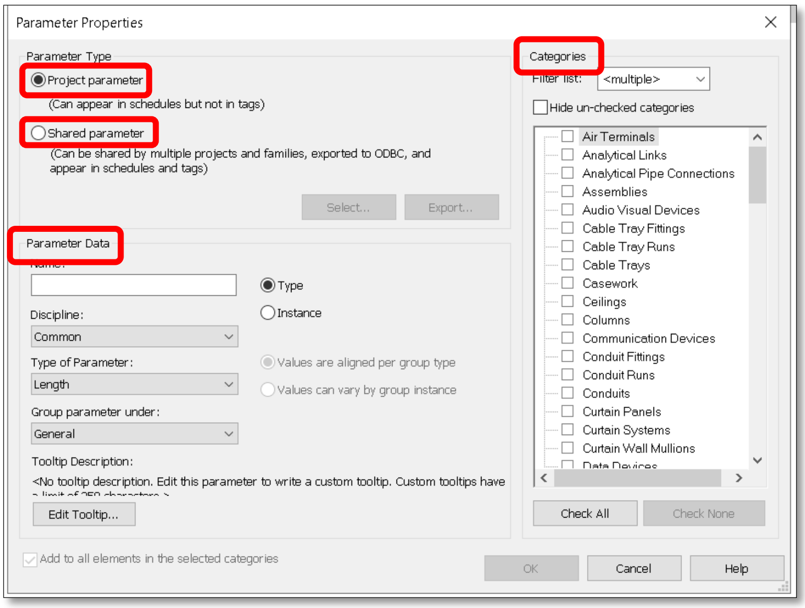


Figure 42 - Parameter properties dialog Classification Parameters

Shared Parameters vs Project Parameters

Parameter definitions that can be used in various families or projects are known as shared parameters. Shared parameter definitions are saved in a file that is separate from any family file or Revit project, allowing you to access it from multiple families or projects. It must be a shared parameter for information in a parameter to be used in a tag. When you want to make a schedule that includes several family categories, shared parameters prove to be very helpful (Autodesk, 2018).

Table 60 presents the shared parameters and projects parameters characteristics:

Table 60 – Shared parameters and project parameters comparison

Shared Parameters	Project Parameters
Require creation/management in an external text file (Manage -> Shared Parameters)	Are internally managed within a Revit project (no external file)
Can be added at category level or family level	Are added at category level and may be added to multiple categories
Can be used as Visibility Graphics Filters	Can be used as Visibility Graphics Filters
Can be scheduled	Can be scheduled
Can be tagged	Can not be tagged
Parameters are set up by defining their name, grouping and data type. Instance or type can be defined when applying to a specific family.	Parameters are created by specifying their name, grouping, data type, and applicable categories. Similarly, the parameter's instance/type level is set when it is created.

7.2.2.12. Classification Parameters

As mentioned before, Uniclass 2015 classification shall be used in the company and all content must have the following parameter with the correct Uniclass reference from “Table L-Products” or Table G-Systems”.

Table 61 - Classification Parameters

Parameter Name	Example Value	Description
ClassifcationName	Uniclass2015	Name of the classification system for example Uniclass2015
ClassifcationValue	Pr_40_50_21_60	Classifications value of the object

Assigning Classification in Revit

The Uniclass 2015 Assembly Code should be assigned to each family type. This can be done in two ways.

-The first way to assign classification to each object is to use an assembly code text file containing Uniclass 2015 codes. To do this, take the following steps:

1. Download the assembly code text file for Uniclass2015. Latest update might be reached at https://digital-guerrilla.scot/downloads/.

2. Upload it into the Revit project using “Mange” tab ► “Additional Setting” ► “Assembly Code”.

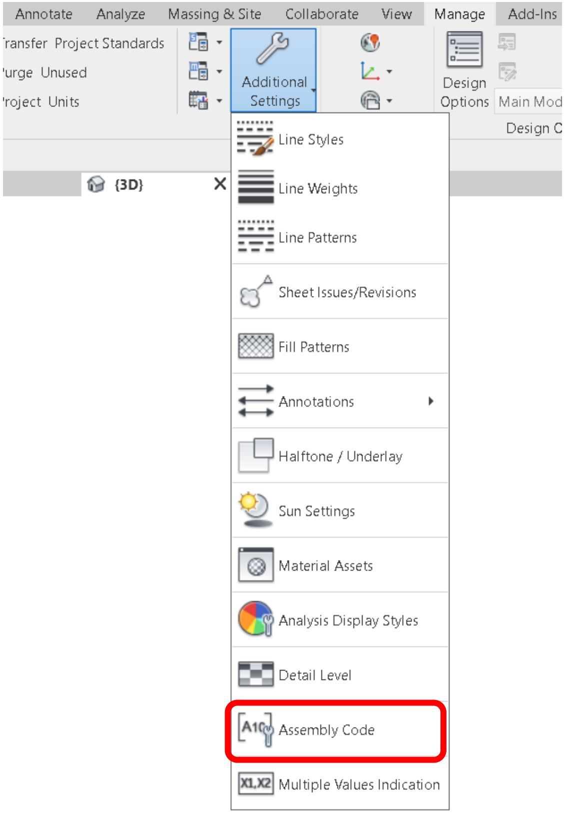


Figure 43 - Assembly code under Additional Settings

3. Click on “Browse” and select the assembly code file(.txt) that you have downloaded. By clicking on the “View”, the classification file and its data tree can be found in Figure 45.

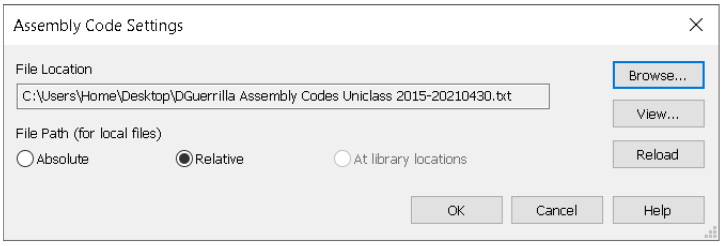


Figure 44 - Assembly code setting to upload the classification text file

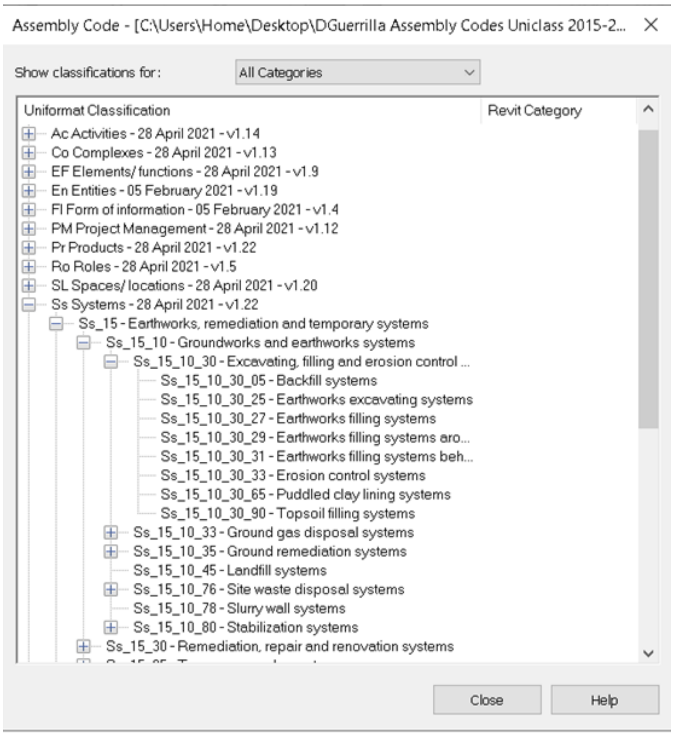


Figure 45 - The classification data tree

4. Select an object and open the Type Properties dialog for the family.

5. Under Identity Data, for Assembly Code, click in the Value field, and click the browse button to select the appropriate Assembly Code from the dialog.

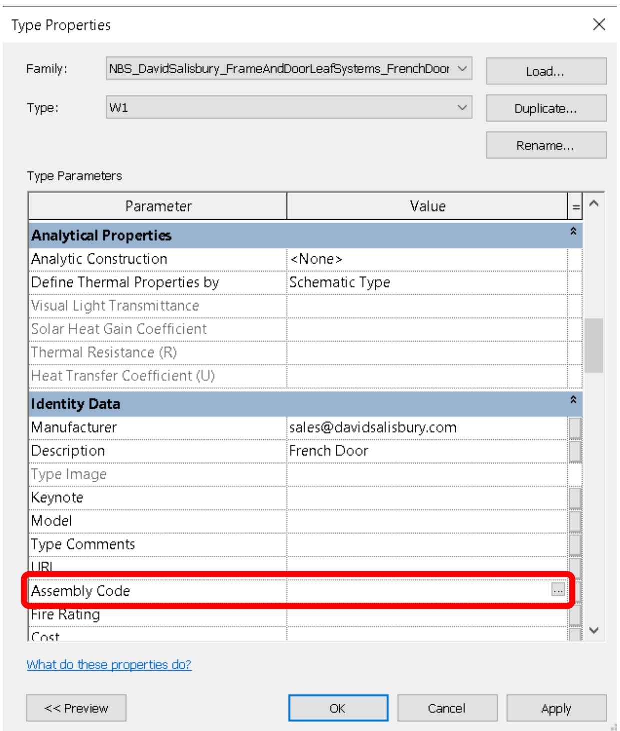


Figure 46 - Assembly code in type properties

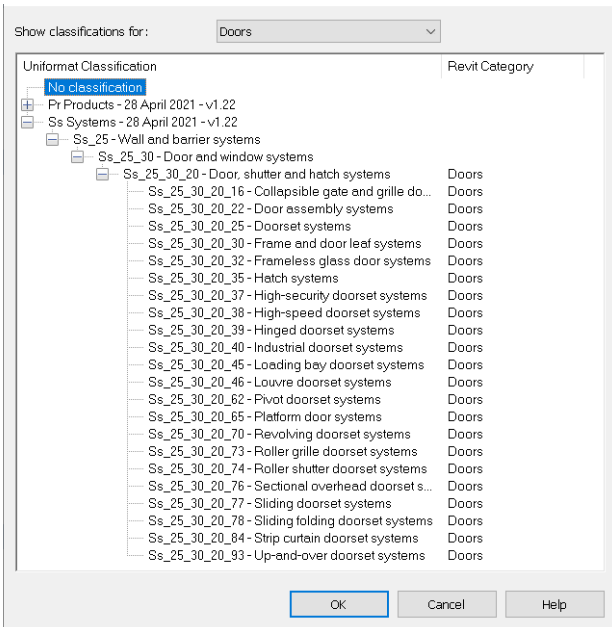


Figure 47 - Classification data tree to choose the appropriate Assembly Code for the object

- Another route to assign the classification is to use Revit Classification Manager. It easily allows organisation and management of classification data across all your Revit models. To do this, download and install the BIM Interoperability Tools add-in and perform the following steps:

1. Select “Setup” from the “BIM Interoperability Tools” tab to select a classification database.

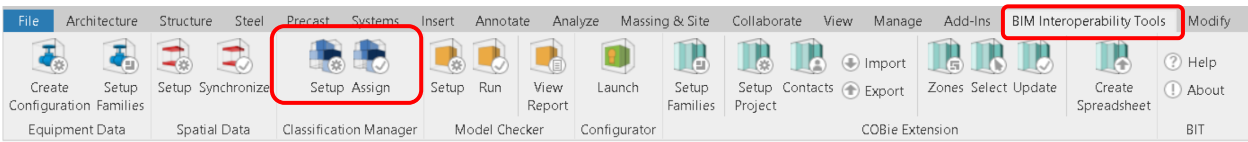


Figure 48 - BIM Interoperability tools add-in

2. Select the “Uniclass 2015 Database” and click Finish.

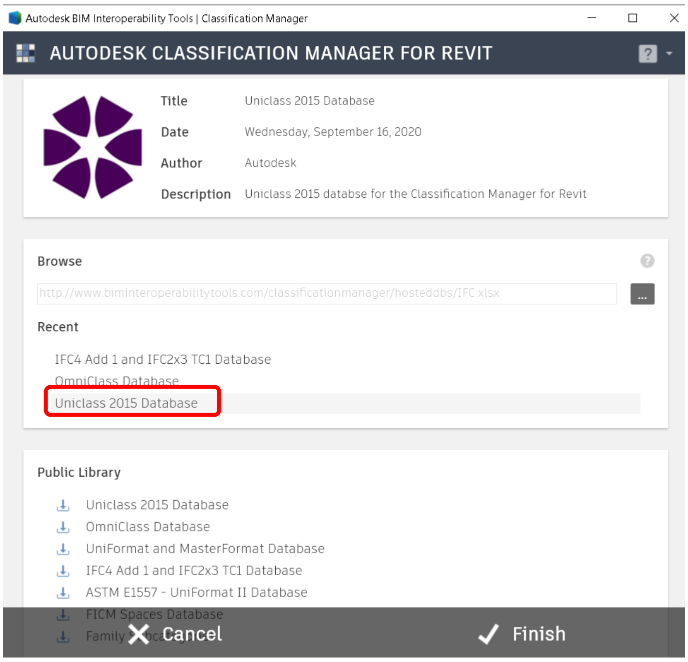


Figure 49 - Setting up the classification system

3. select the elements in the Revit model and select “Assign” from the “BIM Interoperability Tools” tab.
4. Click on “Element”on the left. The relevant tab and filter will be applied to your list of classifications to utilize, based on what type of element you selected. Choose the classification that most suits the selected element.

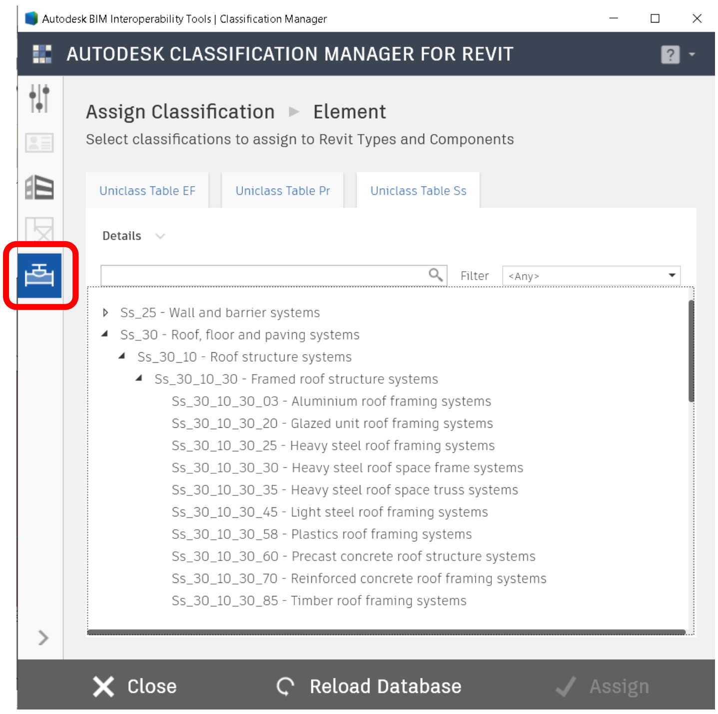


Figure 50 - Assigning the classification system

7.2.2.13. IFC Parameters

By adding IFC parameters you will increase the overall effectiveness of the 'Revit to IFC' export process. When Revit exports to IFC, it handles the minimum IFC parameter requirements; however, adding the parameters below will increase accuracy and interoperability with other platforms that may use the exported IFC.

Table 62 shows the minimum requirements for the objects to be exported to IFC. Ensure that IfcExportAs and IfcExportType parameters are saved under the 'IFC Parameters' category in Revit.

Table 62 - Objects IFC parameters

Parameter Name	Example Value	Description	Type
IfcExportAs	Desk	The Export type	Mandatory
IfcExportType	IfcFurnishingElementType	The IFC export Type	Mandatory
NominalLength	800	Nominal Length	Optional
NominalHeight	900	Nominal Height	Optional
NominalDepth	600	Nominal Depth	Optional

Assigning IFC Parameters in Revit

Similar to signing classification explained in the previous part, the BIM Interoperability Tools add-in can be utilized to assign IFC parameters to the elements.

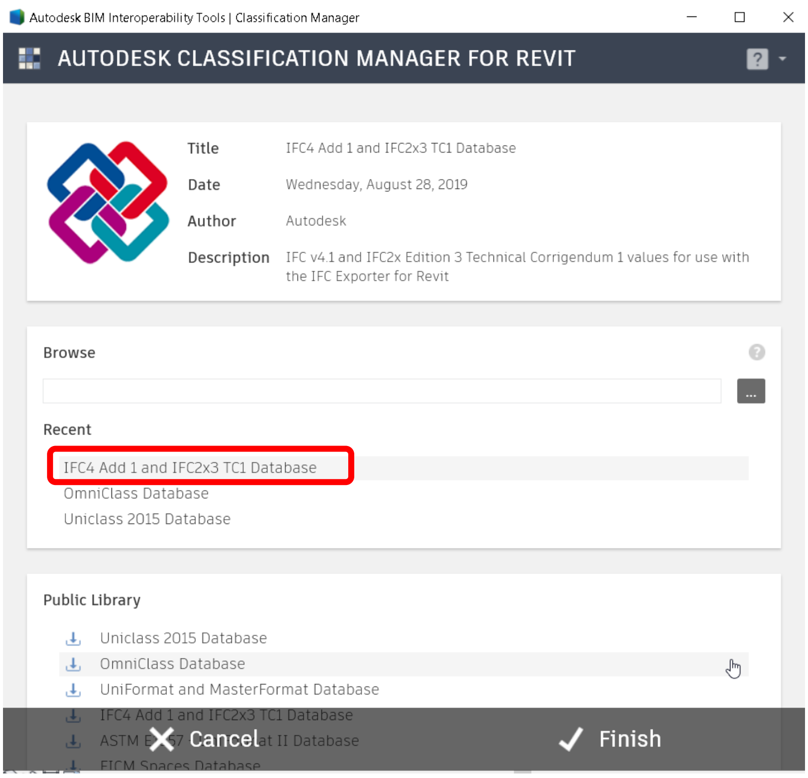


Table 63 - Setting up IFC database in BIM Interoperability Tools

Another method to add IFC parameters is the usual way of assigning parameters to objects explaining in Parameter Usage.

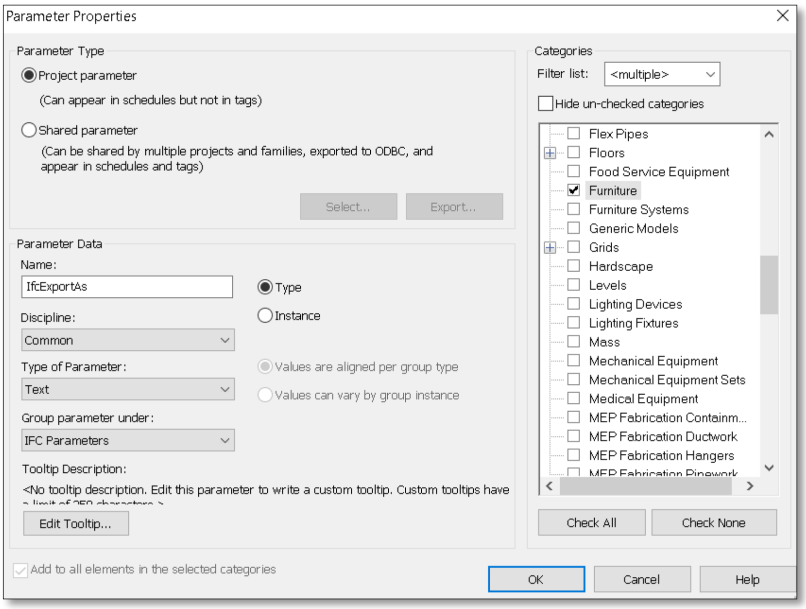


Figure 51 - Assigning IFC parameter in Parameter Properties

7.2.2.14. Material application in model families

Materials can be applied to families to depict the real-world display of elements created with the family in shaded and rendered views. It can be controlled the user's ability to edit the materials of elements created with the family by how materials are applied to the geometry of the family. To apply materials to family geometry, these guidelines should be followed:

Table 64 - Object material guidelines (Bimstore, 2020)

If you want to...	Then...
use materials that will not need to be changed	Option 1 - Apply the material directly to the family geometry by assigning it to the Material parameter
Use materials that will not need to be changed	Option 2 - Apply a material to the family category create subcategories, assign materials to each subcategory, and assign subcategories to geometry
Change the material for a geometric component in a family by instance or type	Option 3 - Create an instance or type material parameter and assign it to the appropriate family geometry. NOTE: This is the most flexible and preferred method of material assignment

Option 1 – Apply Materials with the Material Parameter

In the Family Editor, it can be applied materials to some or all of the family geometry. It can be applied materials to the default Material parameter on each piece of family geometry. When the material of the family geometry is unlikely to vary, such as for a manufactured component with a single standard, use this method.

Result:

When elements are created in a project with the family, one´s cannot:

• Alter the element materials without editing the family

• Change the material for instances or types of the family

• Alter the materials by assigning a material to the element category

Option 2 – Apply materials to a family geometry by category and subcategory

Materials can be applied to all or select pieces of family geometry by subcategory.

Subcategories are categories that exist inside the family category. Different pieces of family geometry cab be assigned to each subcategory and then apply a different material to each subcategory. The family category can be used to apply material to geometry that isn't linked to a subcategory.

When one´s wish to be able to apply different materials to different family components based on their category or subcategory, should use this method.

Result: When an element in a project with the family is created:

• The materials assigned to each subcategory or category can be changed.

Option 3 – Apply materials to a family geometry and change using instance/type

It can be created and assigned a custom instance/type material parameter to family geometry.

when applying materials to your family geometry, this is the most flexible option to utilize.

Use this method to allow the user to change family materials by instance or by type. By setting the material parameter to <by category> this option can also allow the elements to be updated by subcategory or category.

Result: When an element with the family in a project is created:
• The parameter gives the option to change a material for an instance of the element or for each type of element that is created (Bimstore, 2020).

7.2.3. Software Template

The section describes the features of a BIM Template for Revit 2022 and provides a step-by-step guide to apply them in projects. However, you can follow along the instructions with another version considering the followings:

- Different versions may differ somewhat from one another.
- Older versions of Revit are unable to open files created with a previous version.

Autodesk Revit comes with the capability to configure, manage, and save standard Revit work environments, as template files. The template is a raw design file with RTE extension. When creating a new project by choosing a particular template, user selects and applies a certain configuration contained in the template. The template file is maintained unaltered, but the new design file is saved with a new extension, RVT.

Templates allow an organization to standardize modelling practices across multiple projects, ensuring that graphic representations, data syntax, object and view taxonomies, and the overall software working environment are consistent, and that the end product meets industry and organizational standards. Creating a good project template will help you to save time because you do not have to load the same elements and perform the same settings every time Each time you start a project.

All Revit projects shall be created utilizing one of the templates developed based on guidelines given in this BIM Guide.

• BIMMS-TEMPLATE ARCHITECTURAL.rte

• BIMMS -TEMPLATE STRUCTURAL.rte

• BIMMS -TEMPLATE MECHANICAL.rte

• BIMMS -TEMPLATE ELECTRICAL.rte

• BIMMS -TEMPLATE INFRASTUCTURE.rte

These templates contain several predefined Starting View, Project Browser, Loaded families, View templates, defined settings such as units, fill patterns, line styles, line weights, scales, text, dimensions, among others.

7.2.3.1. Family Templates

Loadable families shall be created based on family templates with RFT extension. Family template files contain all necessary property sets and define the behaviour of family. There are separate template files for each Revit category. The template choice depends on the category of family to be created.

Examples of family templates:

For model elements: Metric_Window.rft

For annotation elements: Metric_SectionHead.rft

For title blocks: A1_Metric.rft

7.2.3.2. Content Library

As explained in Folder structure section, there are two repositories for the storage of the content: one is the central library and the other is project specific library.

Project specific library contains standards required due to project or client requirements and shall include project templates, titleblocks, families and other data produced in the process of completing the project.

Each family will be saved to an ".rfa" file. Note that only "loadable" families are saved. In-place and system families, such as walls, duct systems, and patterns, will not be saved.

7.2.3.3. Using the Revit Template

Save a copy of the Revit Template file in the project library folder. Only authorized users will be able to make changes to the template file if the folder is secured. The template file is normally only used once, at the start of the project BIM development, when initiating the project Revit file. It's usually kept in the project folder alongside other reference files.

To start a new Revit model based on the provided template, in the Revit work session, select "New...", browse to the directory containing the Revit Template, select the Revit Template, and click open. Once opened, save as a new Revit project file (.rvt) with the appropriate naming addressed in Naming Conventions section and start working.

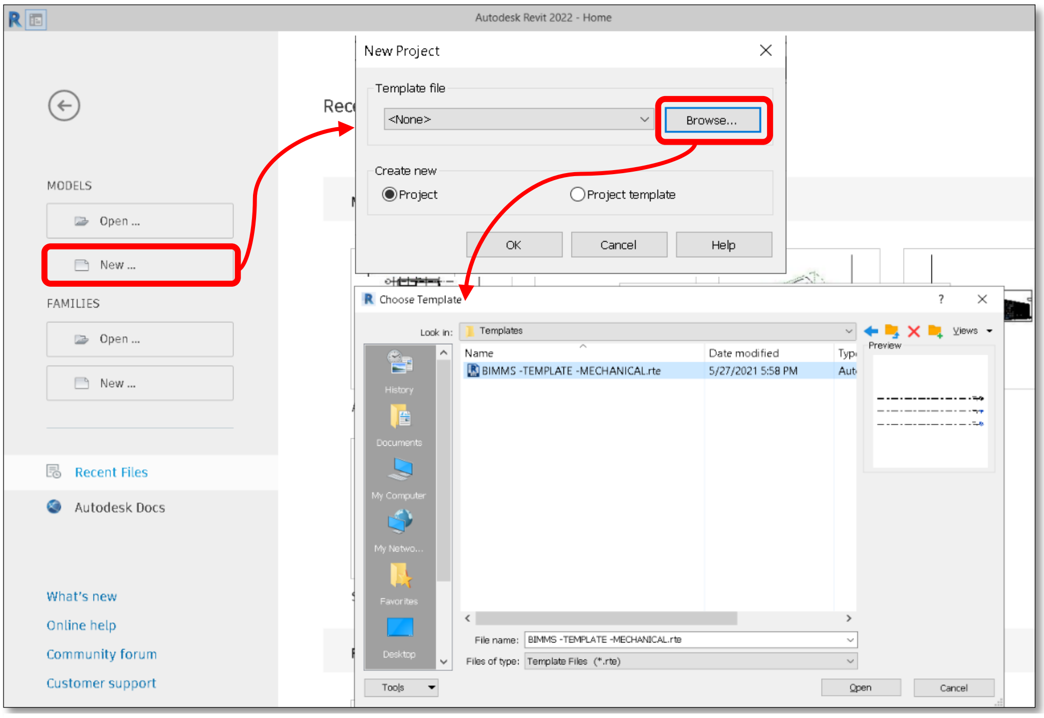


Figure 52 - Opening a template in Revit

7.2.3.4. Project Information

This element changes project by project and relates to a project template. It contains the information that is associated with this particular project and it might be found under "Manage" tab.

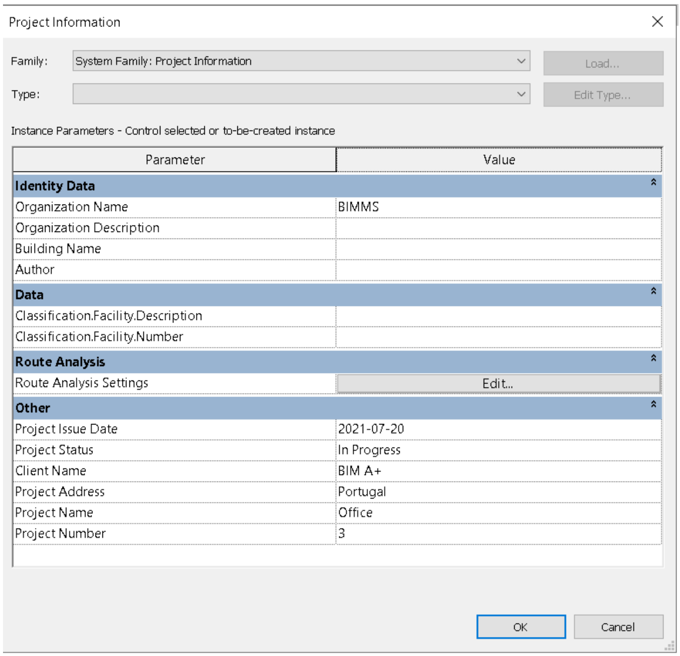


Figure 53 – Project information dialog box

7.2.3.5. Starting View

The view that Revit displays when a particular model is opened might be determined. The Starting View is set using "Manage" tab ►"Starting View" icon. This brings up the Starting View dialog box, where it was chosen the view wanted to set as the starting view from the drop down.

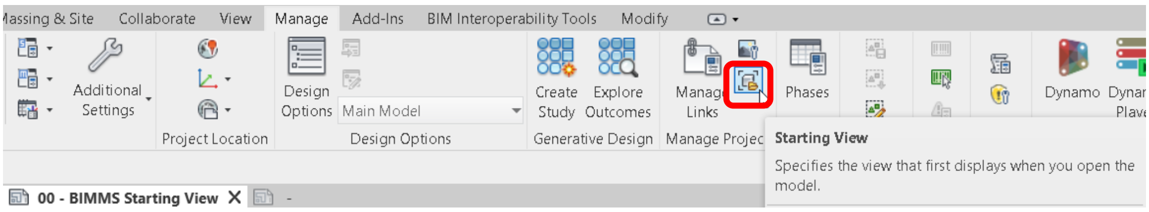


Figure 54 – Starting view icon

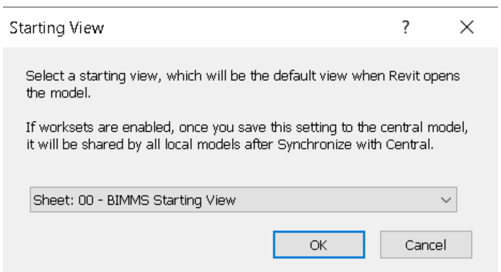


Figure 55 – Selecting the starting view

A sheet labelled “00 – BIMMS Starting View” has been created as the initial opening sheet for the project template. The sheet comprises general project information and uses that are linked into the Project Information Attributes. Additional user instructions may be included on this sheet. The opening sheet is set up to allow users/managers to add notifications or messages to people involved with the project.

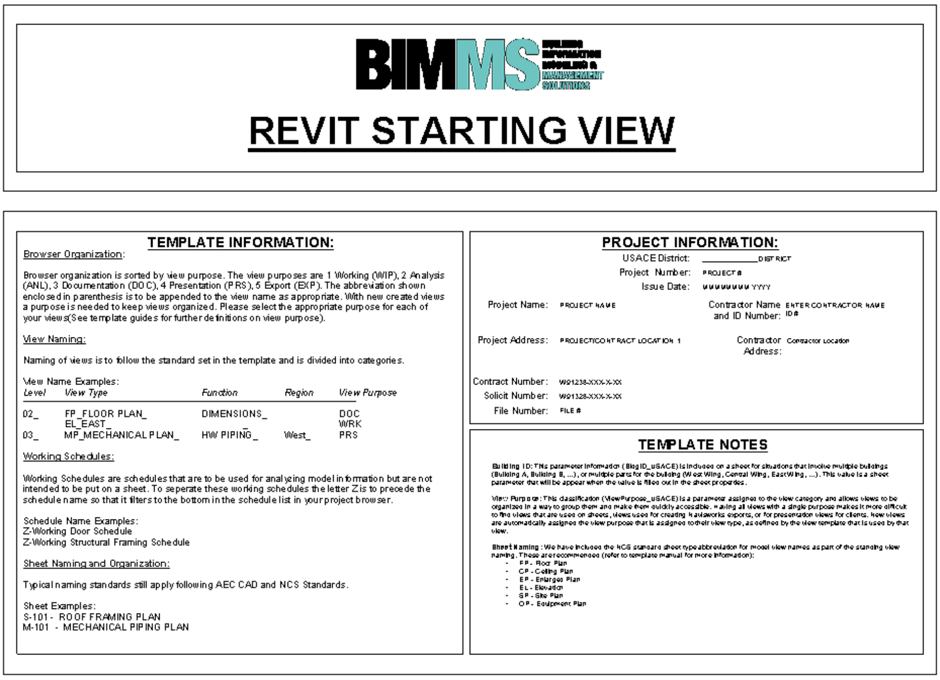


Figure 56 – The company template starting view

7.2.3.6. Project Browser Organization

The project browser contains the structure organization for BIM submission. The company Revit templates contain basic Revit views as a starting point for developing the project model. Each basic view of the model (for example floor, reflected ceiling, elevation, section, etc.) should follow the view naming rules provided in Naming Conventions section.

Managing Project Browser is particularly helpful in big projects with many views. The views might be filtered and grouped.

Project Browser might be organized by right clicking on Views (all) then click Browser Organization.

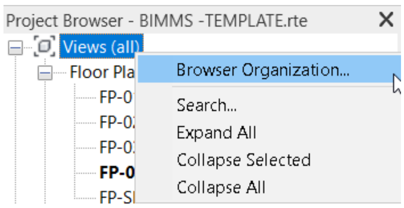


Figure 57 – Project Browser organization

In the Browser Organization, there are three tabs: Views, Sheets, and Schedules. The settings for Views and Sheets are similar. There are several default organizations, that might be added or modified. Except for "All" that the organizations cannot be edited.

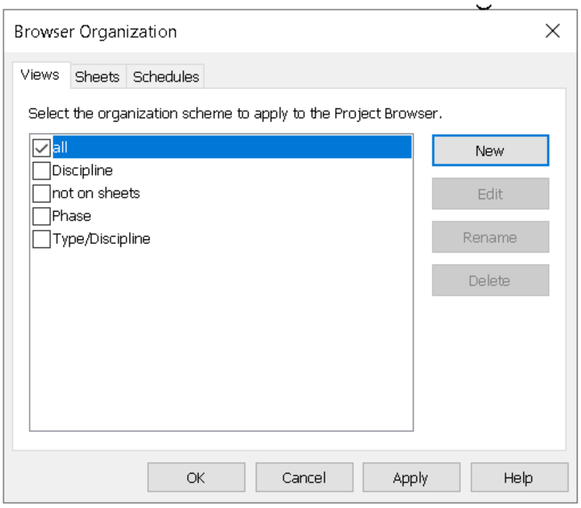


Figure 58 – Browser organization dialog box

Organizing Views

As the project gets bigger, it becomes more difficult to find the view that you want.

Filtering

For Views, it can be selected Discipline then Edit (Figure 58). The first tab in the Browser Organization Properties is Filtering. It allows to filter based on specific floor plans, discipline, or a specific phase. It can simplify the list in your Project Browser and avoid the confusion.

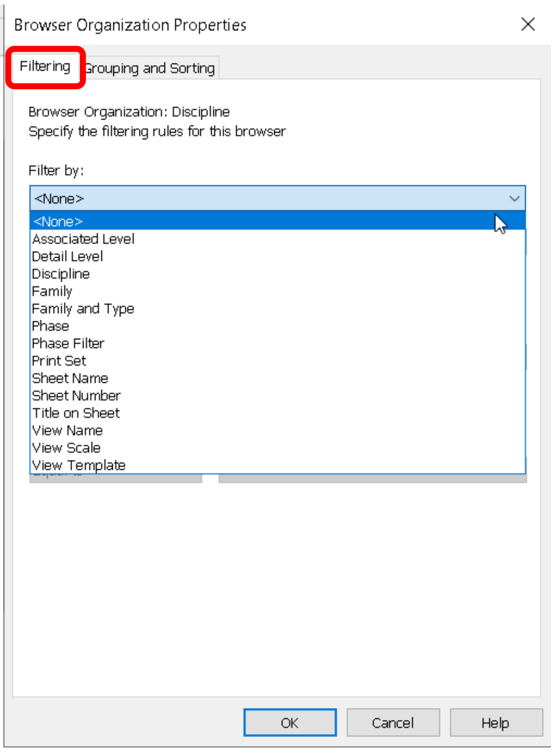


Figure 59 – Filtering tab in project browser

For example, in Figure 60, the Project Browser is filtered in a way to only show coordination and mechanical disciplines.

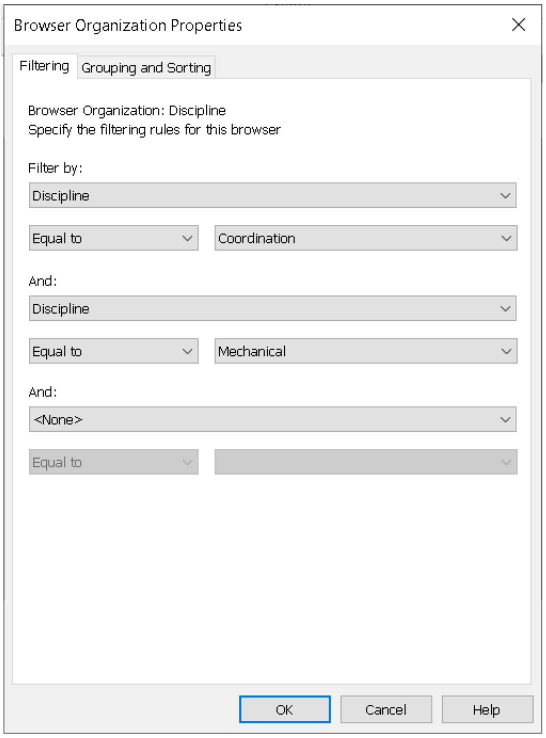


Figure 60 - Filtering project browser

Grouping and Sorting

The Grouping and Sorting tab can be used to further group the views and arrange them by another property.

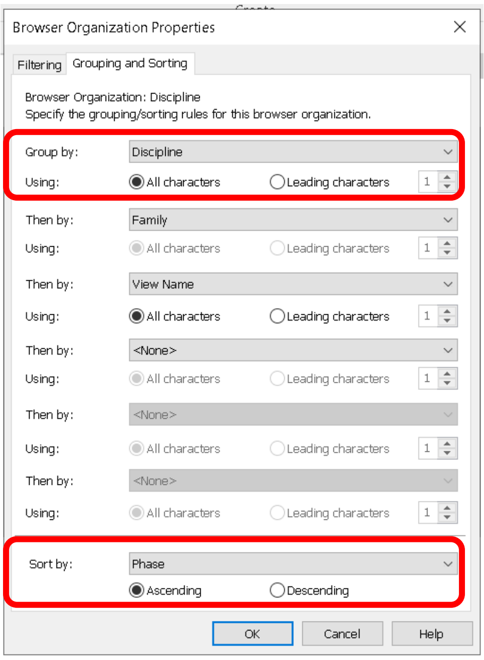


Figure 61 – Grouping and sorting project browser

Organizing Sheets

For Sheets, it is also possible to filter and group them for an easier access.

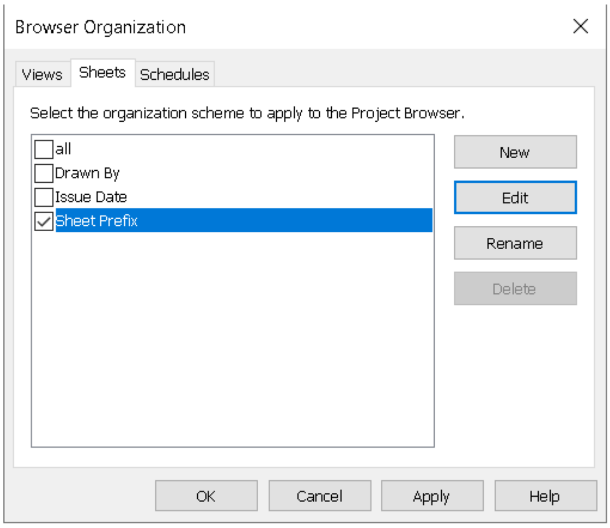


Figure 62 – Browser organization for sheets

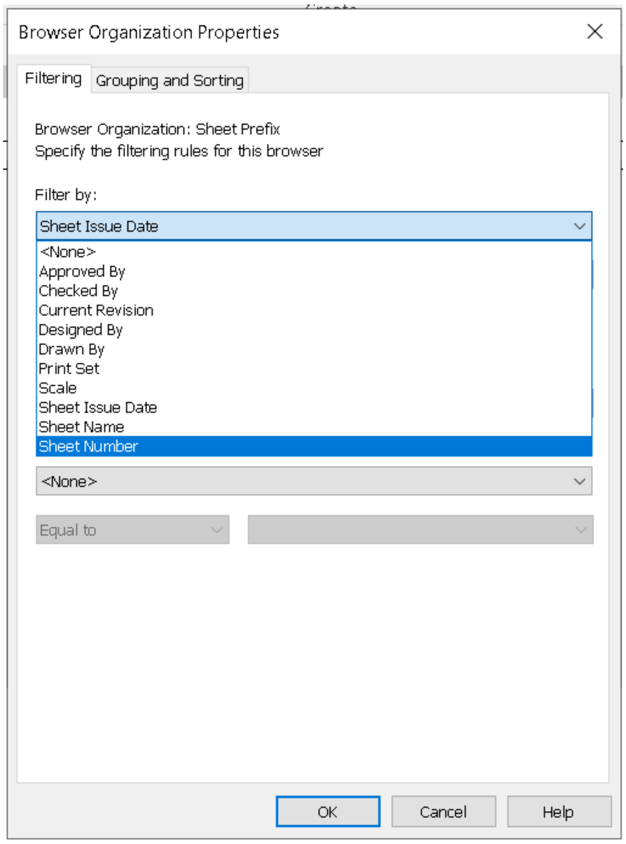


Figure 63 – Filtering sheets in project browser

7.2.3.7. View Purpose

It is recommended to have a custom project browser to separate the purposes of the views. In the template proposed in Figure 64, ISO methodology is considered by having WIP and PUBLISHED views. Another view category is COORDINATION views that all are explained below.

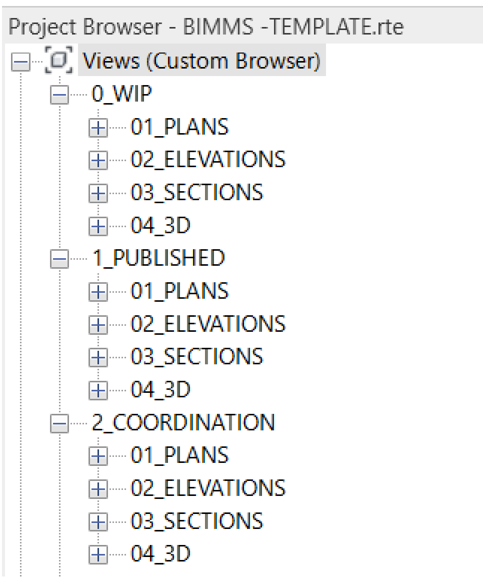


Figure 64 – Project browser view template

WIP (Work in Progress) Views

This set of views is for the main design and layout of the building. These views are not supposed to be utilized for final documents and are used to support the modelling process.

Published Views

These views are complete and ready to be placed on sheets. Published Views may contain scope box views for larger projects. Only relevant categories and objects are displayed using the appropriate visibility and/or filter settings.

Coordination Views

These views are used to coordinate and collaborate with other disciplines, including civil, interior design, structural, MEP, and landscaping. Collision detection between disciplines would be done here.

Alternative view purposes shall be required based on the project and added into the project template at the beginning of the project.

7.2.3.8. View Templates

The company Revit Template has been set up with several customized view templates to ensure consistency and appropriate visibility of objects for certain types of views.

Each "view template" has its own set of settings that determine how BIM objects appear. View properties such as View Scale, Overrides, Model Display, Shadows, Lighting, View Range, and others are included in these settings.

Using the “View Templates” under “View” tab, a new template can be created base on the setting defined on the current view.

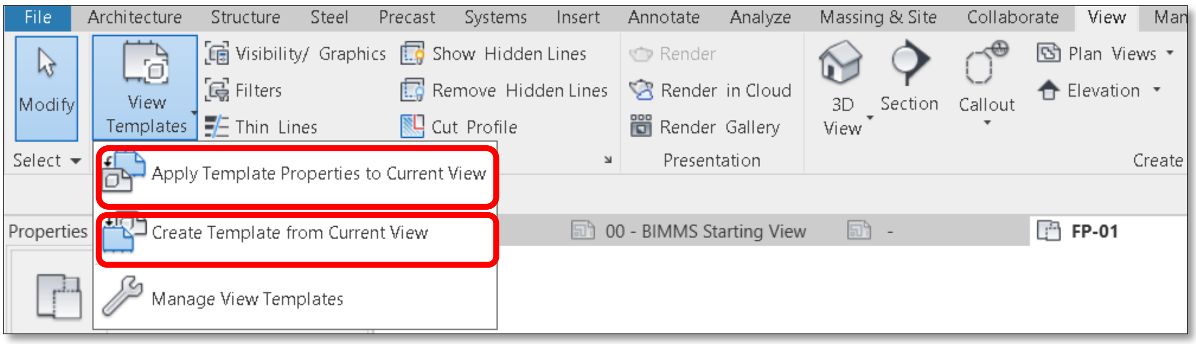


Figure 65 – View template icon

To apply a view template to a specific view, select the view and

1) click on the “Apply Template Properties to Current View” (Figure 65) or;

2) click on the “View Template” on the “Properties” and select the desired view template from the list (Figure 66) or;

3) Select the view or multiple views in the browser window and right click and select Apply Default View Template.

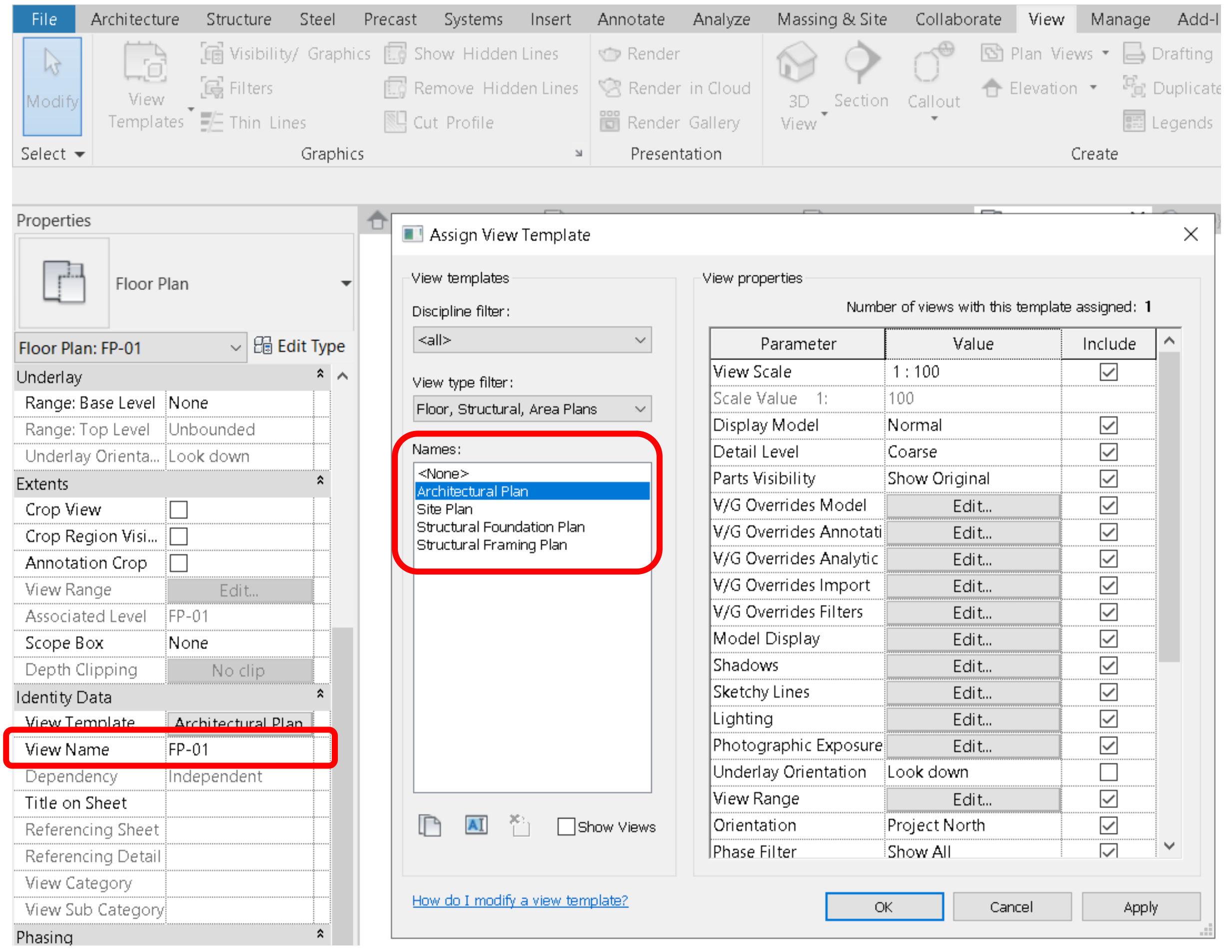


Figure 66 – Selecting view template using properties

7.2.3.9. Shared Parameters

A shared parameter file template is a text file in the project content library. Shared parameter files help the consistency of naming. As an example, name a parameter as “Height” instead of “H” or any other name and save it in the project library. By importing the same parameter of “Height” into multiple files, it will result in the consistent schedules, tags, applications of formula, conditional IF statements etc.

By checking Shared Parameters in the Parameter Properties, it is needed to select the text file from the library, select the group and choose the category of the parameter.

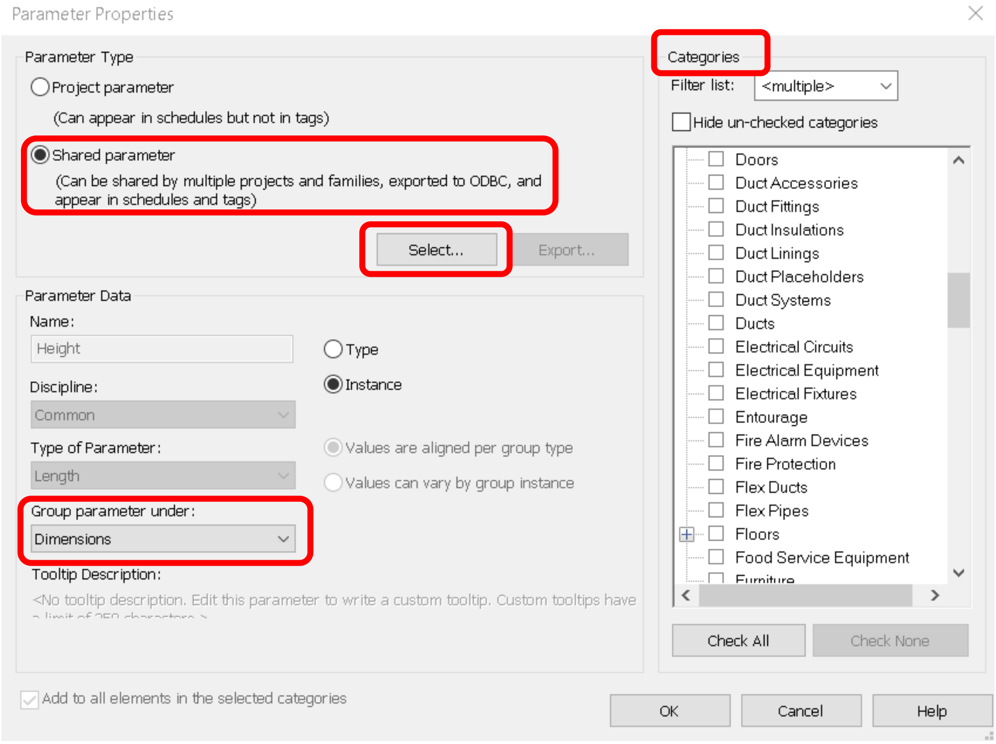


Figure 67 - Share parameter selection

7.2.3.10. Phases

Phases can be created to match the Project Phases as necessary. Revit tracks the Phase in which elements are created or demolished and lets you use and create Phase Filters that can be applied to Views so that different stages of work can be displayed in different Views.

Phases icon is accessible under “Manage” tab ► “Phases” icon.

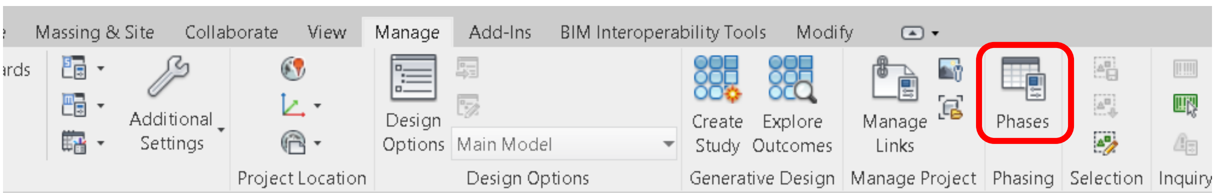


Figure 68 – Phases icon

Phase Status for Existing, Demolished, New and Temporary have been set as shown in the table below, and the graphic overrides for each phase shall be defined in the project template.

Table 65 – Phase status

Phases	Description
Existing	Element was created in an earlier Phase and continues to exist in the current Phase
Demolished	Element was created in an earlier Phase and demolished in the current Phase
New	Element was created in the current Phase and will not be demolish in the current Phase
Temporary	Element was created and demolished during the current Phase

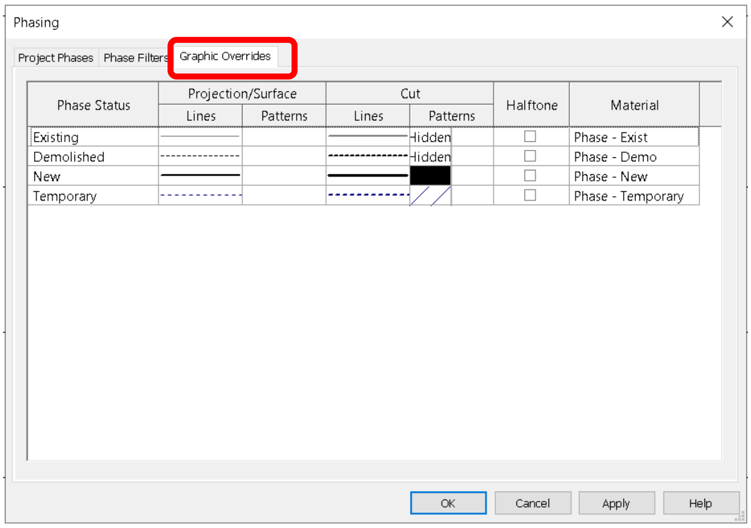


Figure 69 – Phasing dialog box

7.2.3.11. Annotation Elements and Graphical Settings

Annotations and Symbols shall be placed in each View (if applicable).

Generic Annotation, Tags, Symbols, and Callouts, among other Annotation symbols, are pre-loaded within the Templates based on the Discipline.

It is recommended for each template of the company to be set up with the views that places around a 100-meter grid to have enough space for the modelling.

A square starting from the base Project Base Point/Survey point on the left bottom corner has been established as the modelling space and is consistent between the templates. This will provide a consistent starting environment for the models. This also provides a positive starting point for the model.

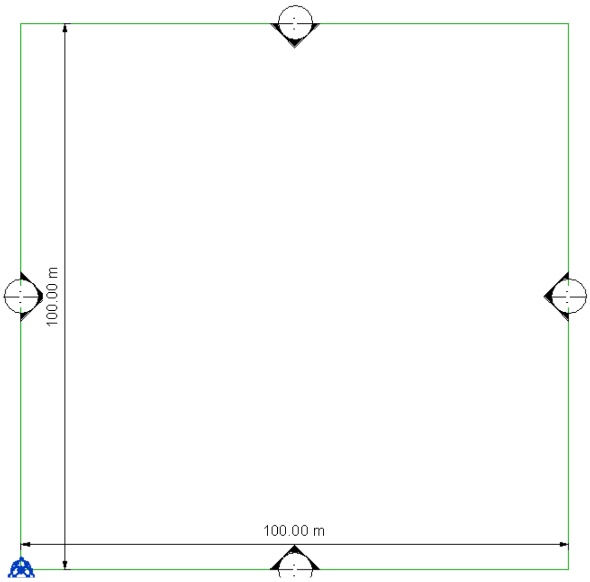


Figure 70 - The template work area

Lines – In engineering documentation, lines are one of the most basic graphic elements. A template is an excellent place for developing the line patterns, weights, and styles that will be used in your project. Line patterns can only be created using dashes, spaces, and points. Using Line weights users can define the width of the pen when printing out the objects. Line styles are a combination of line patterns, line weights, and colours. From the Manage tab, click on Additional Settings and here you can find Line Weights, Line Styles, and Line Patterns.

Text and dimensions – Text and dimensions - the next two basic aspects of any documentation are text and dimensions. For the appearance of the text contained in the drawings, many projects have predetermined standards.

Arrowheads – another graphic element that can be found in almost all documentation. It is good to have a specific list of standard arrowheads in the company/project template.

Tags –There are elevation, section, callout, and model object tags that the company uses in the projects and should be added to the template.

Fill patterns and materials – A specific set of fill patterns and materials that mostly used in the company's projects can be added to the template. If your office works on a variety of projects and specializations, however, strive to maintain the number of patterns and materials to a minimal.

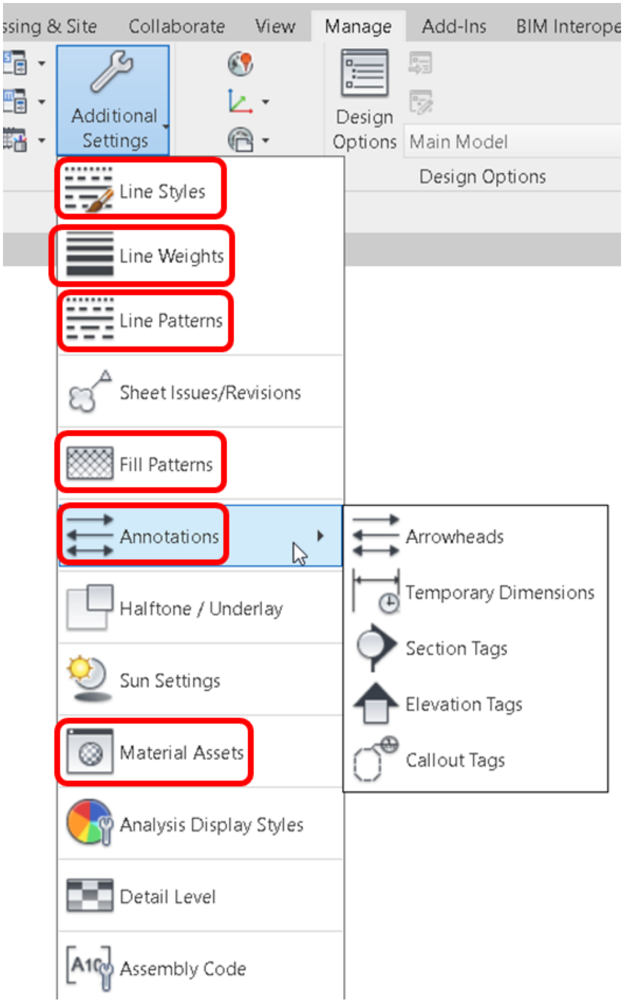


Figure 71 – Annotations and graphical commands under Additional Settings icon

7.2.3.12. Schedules

A set of schedules are included in the Revit template to track information that is required as a part of the standard project BIM deliverables.

Specific pre-defined quantity Schedules in the BIMMS Revit Template are the schedules which are mostly used by the users and can include:

1. Doors, Windows, Walls, and Finishes

2. Column, Framing, Floor and Foundation

3. Schedules for reference or documentation

7.2.3.13. Sheets

A well-structured set of predefined sheets which include a proper scale, paper size, and title block shall be provided in the company/project template library.

Creating a New Sheet with a Title Block

To create a new sheet:

Select the View tab the Sheet Composition panel Sheet icon,

Or select and right click on the Sheets in the Project Browser and select New Sheet...

In the New Sheet dialog box, select the company template title block from options listed or load it from the template library and click OK to create a new sheet.

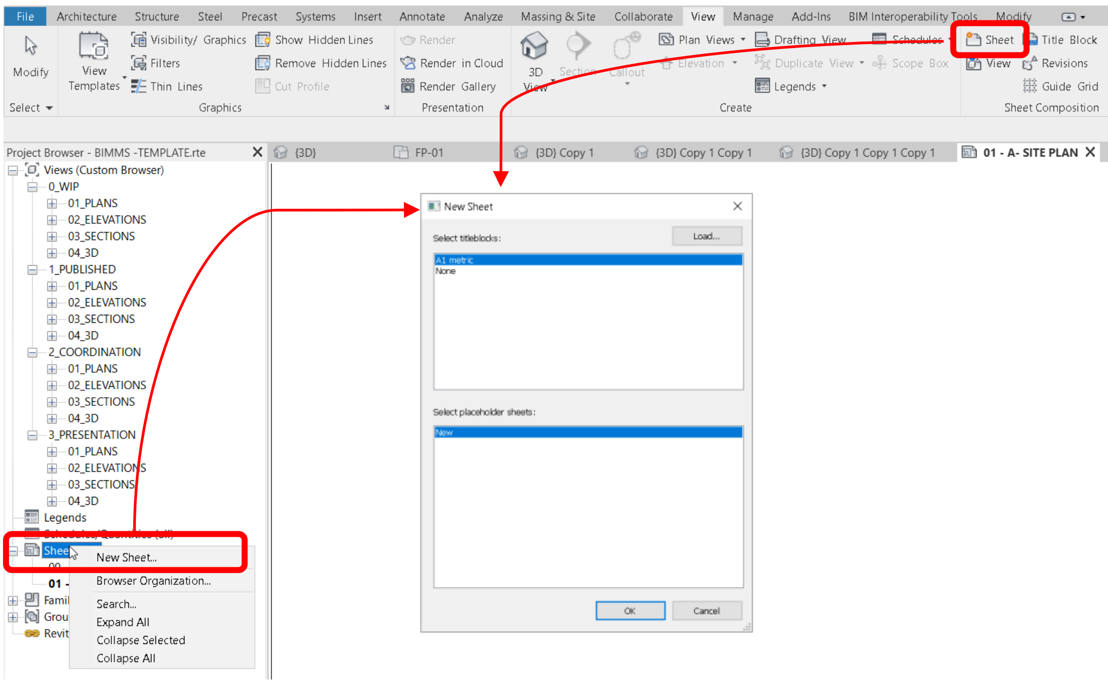


Figure 72 – Creating a new sheet with a titleblock

Adding Properties to the Sheet

In the Revit Properties palette, complete the information for the fields in the Properties window. These parameter entries feed the sheet title block with sheet-specific information.

Adding Project Information to the Sheet

On the Project Information dialog box as described in 7.2.3.4 Project Information section, fill in project specific data. This information will be displayed in the title block.

7.2.4. Modelling Procedures

This guide highlights that projects are unique, each with different drivers and project owners with specific modelling standards and protocols. As a basic minimum, each discipline in the project team should follow industry-proven best practice approach and adhere to in-house standards and protocols. The appointing party may also have specific modelling and documentation requirements and standards to which they must adhere.

7.2.4.1. Project Setup

7.2.4.1.1. Model Orientation

A True North direction should be indicated in BIM models and the BEP must define Project North rotation angle relative to True North. All models and documents shall follow the Project North orientation and location.

In the Properties dialog, for Orientation, select Project North, and click Apply.

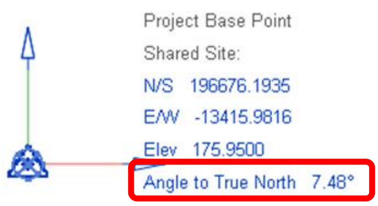


Figure 73 – Project north orientation

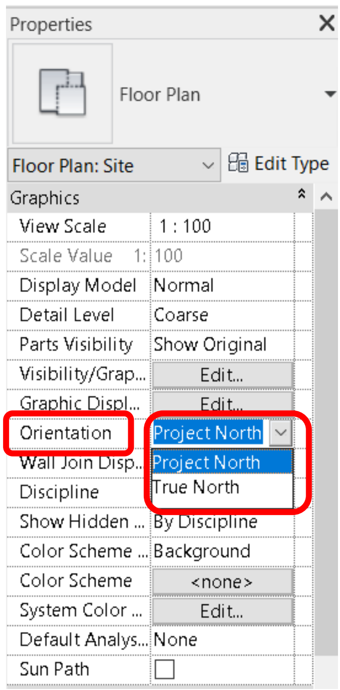


Figure 74 – Model orientation in Properties

7.2.4.1.2. Model Coordinates

The company models are required to be correctly placed in 3D space using the real-world coordinate system. Every project has a survey point (SP) and project base point (PBP). Site base point or survey point provides a measurable location in the physical world to help correctly orient the building. The survey point should also include the elevation of the point. The origin (0,0,0) of the project coordinate system is defined by the project base point.

Figure 75 – Model coordinates

The survey point and project base point might not be always visible because of visibility settings and view clippings, and should not, in any case, be deleted. Use Visibility/Graphic dialog box under "Model Categories" ►"Site" to turn them on.

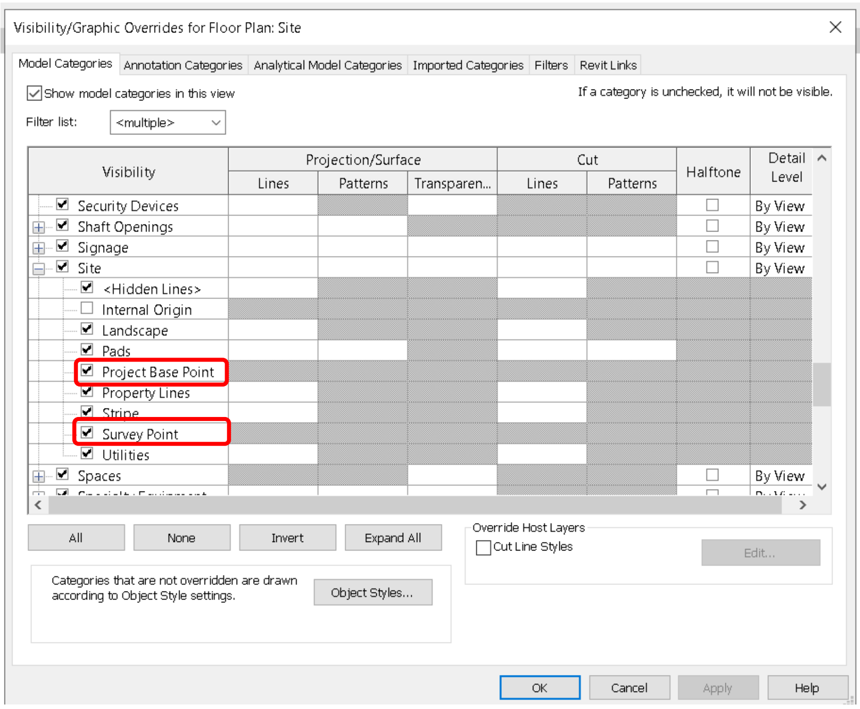


Figure 76 – Checking the visibility of SP and PBS

The PBP and SP need to be the same to align models from different disciplines on the project, using the Revit origin-to-origin command.

The PBP should be pinned at 0,0,0 so that it cannot be moved or deleted accidently.

• The SP coordinates, elevation, and angle to true north must be shared with all disciplines. It must be located at the same point for all discipline model files.

7.2.4.1.3. Shared coordinates

Shared coordinates can only be derived from one file and it is recommended to create one reference model containing coordinates to be shared with model files. BIM Manager should establish the location of the building at global coordinates, true heights, and shared coordinate systems in the reference model.

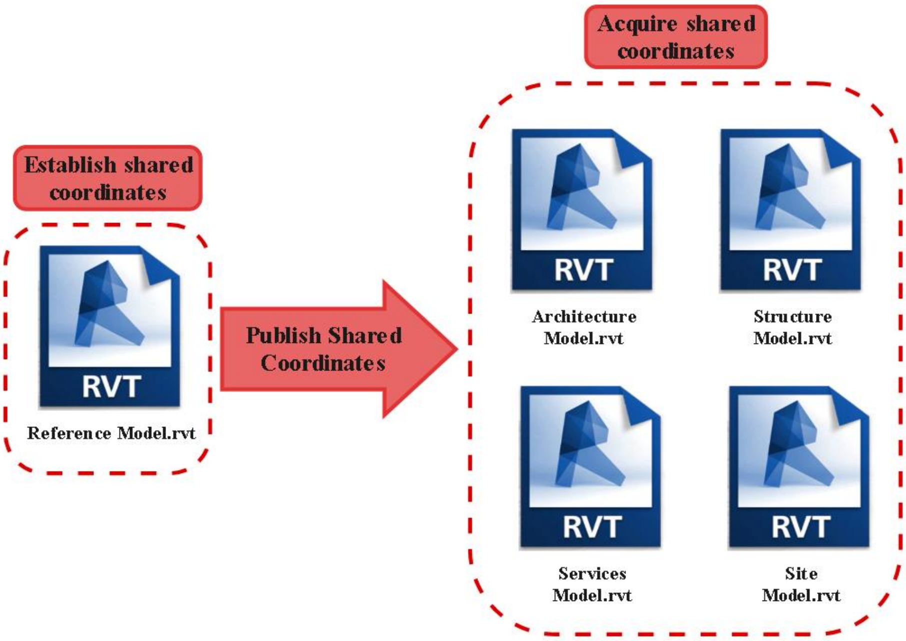


Figure 77 – Assigning shared coordinated

The process to convey shared coordinates to each discipline project files in Revit can be outlined in three steps (Figure 77):

1) create a coordination reference model

Geodetic coordinates, elevations, and north direction are all specified in this file. This reference file also contains the horizontal (column grid) and vertical (levels) divisions. The file may also include survey data and site terrain model.

2) Link discipline models to the coordination reference model

Each linked model acquires shared coordinates from the reference model. The command is under "Manage" ► "Project Location".

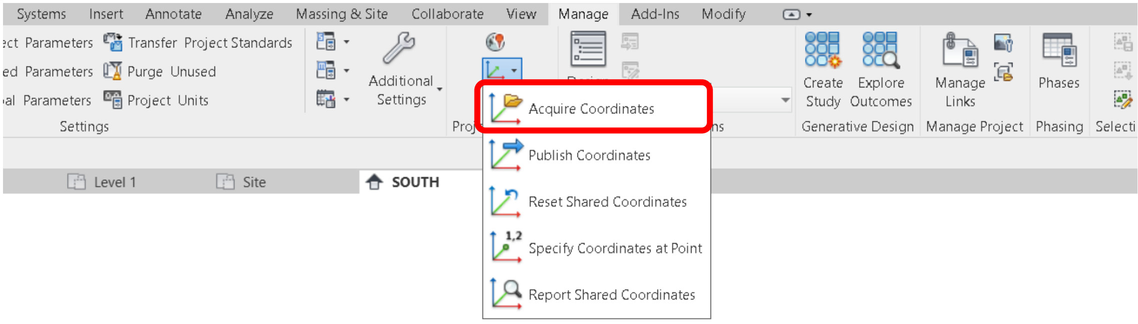


Figure 78 – Acquire coordinates

3) Save shared coordinates back to all the discipline models

Doing this, all the models are now updated and can be used with shared coordinates.

7.2.4.1.4. Levels and Grids

Level tool is used to define a vertical height within a building. The levels are created for each storey or other needed reference, for example top of wall or bottom of foundation. To create levels, one´s must be in a section or elevation view, click "Architecture" tab ►"Datum" panel ► "Level". When levels are added, the associated plan view can be created.

Use the Grid tool under "Architecture" ►"Datum" ► "Grid" to place column grid lines and add columns in the building design. Use letters for horizontal Grid lines and numbers for vertical Grid lines to maintain the consistency. Make sure the levels and grids are stretched to cover the entire construction site.

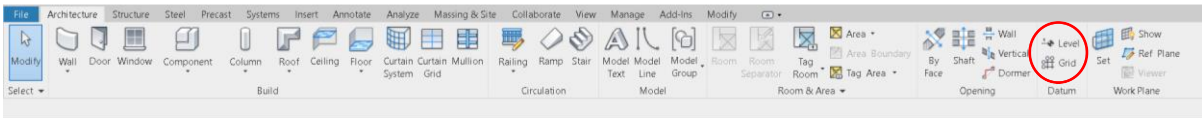


Figure 79 – Level and grid under architecture tab

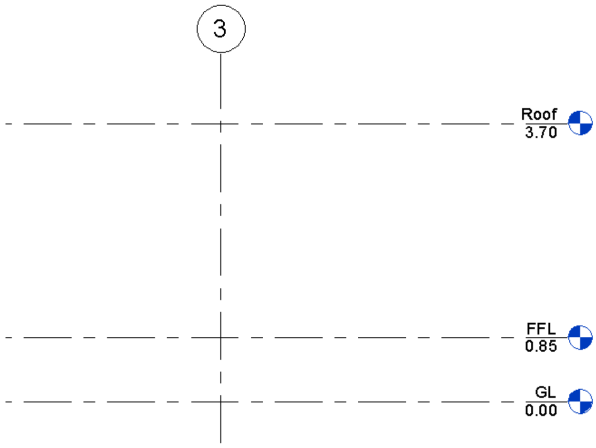


Figure 80 - Levels

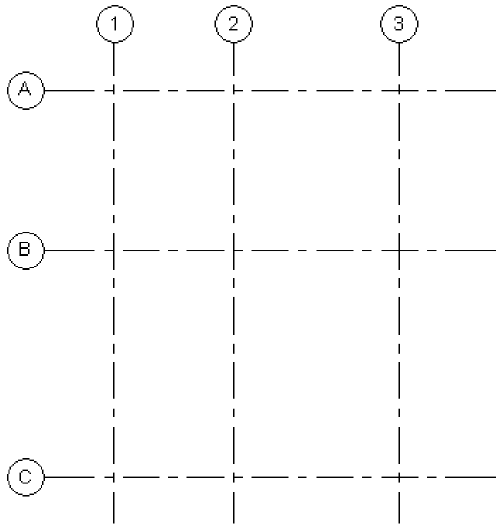


Figure 81 - Grids

7.2.4.1.5. Model Scale & Unit

Models should use consistent units and measurement across the project. The recommendation of this manual for the company is that the models should be modelled in 1:1 true scale, and in metric and consistent units. Common model units used in the company BIM models are as follows.

Table 66 – Model units

Name	Unit	Symbol
Length	meter / millimetre	m / mm
Area	square metre	m2
Volume cubic	metre	m3
Angle	decimal degree	o
Mass	kilogram	kg

The unit of metres with three decimal places for infrastructure projects and millimetres with two decimal places for building projects should be used to obtain a sufficient level of accuracy.

In case of requiring a higher level of accuracy, for example for fabrication, more tolerances should be applied in those areas or building system components.

The angles are measured in degrees, and the precision is two digits after the decimal point, subject to each discipline's guidelines.

7.2.4.1.6. Model Division, Link, and Federation Strategy

It is not advisable to construct a single large BIM model that has all details from several disciplines. Instead, a BIM model should be divided into appropriate discipline, feature, location, and level by the project BIM team.

According to ISO 19650 series, information container breakdown structures are important concepts in managing information models. Defining the information container breakdown structure enables multiple appointed parties to create information simultaneously within different containers in an efficient manner. This simplifies information exchanges while also eliminating the danger of them overwriting each other's information. The federation strategy is a higher-level explanation of how and why the information model is divided up via the information container breakdown structure to facilitate information generation and management (UK BIM Alliance, 2019).

Federation and information container breakdown should be used to:
— allow different task teams to work on different parts of the information model simultaneously without introducing coordination issues, for example spatial clashes or functional incompatibilities;
— support information security;
— ease information transmission by reducing the sizes of individual information containers Standard (BSI, 2019a).
Figure 82 presents the model breakdown structure recommendation based on ISO 19650-1.

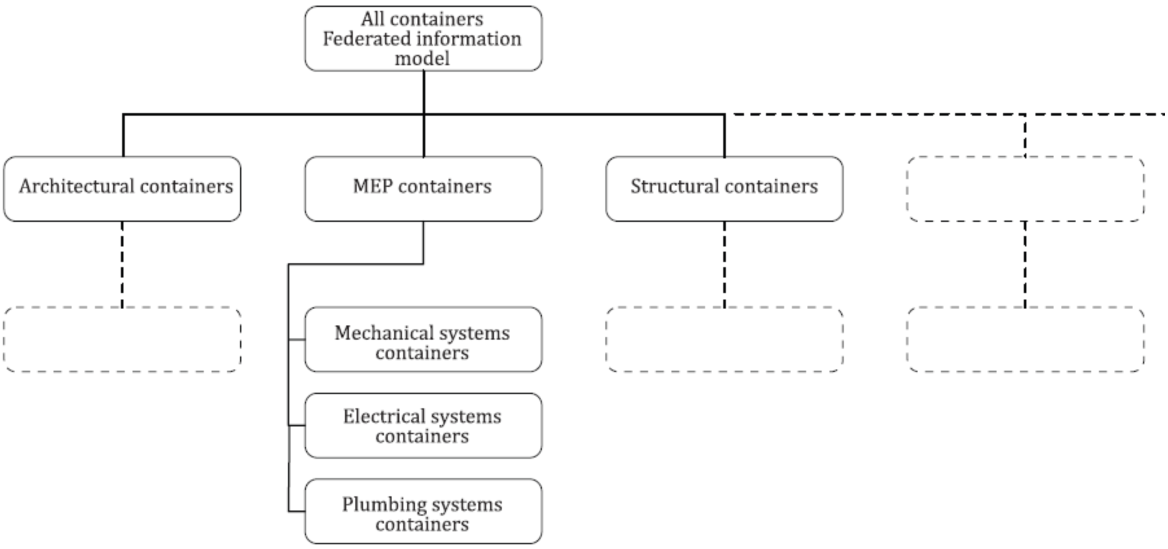


Figure 82 - Illustration of information container breakdown structure for simultaneous working Standard (BSI, 2019a)

Table 67 recommends model division principles for each discipline.

Table 67 - Model division principles for each discipline

Discipline	Division principles
Architectural	By floor
Structural	By functional joints, grips of concrete and metal structures
MEP - Mechanical	By system: air supply, air exhaust, air conditioning
MEP – Plumbing	By system: cold water supply, hot water supply, water waste

To provide updated information and minimize the risk of data loss, all project stakeholders should regularly save and synchronize their models with central location to other participants.

BIM models of different disciplines and projects that are developed in separate files can be linked together into a single model file for ease of collaboration / viewing. Using links in your designs allows you to take advantage of additional geometry and data. A model containing Revit links is called federated Revit model. Checking for collisions is the major goal of the federated model creation.

In order to properly link BIM models, the base point and orientation in all relevant BIM models should be properly aligned to ensure the geo-locations are consistent.

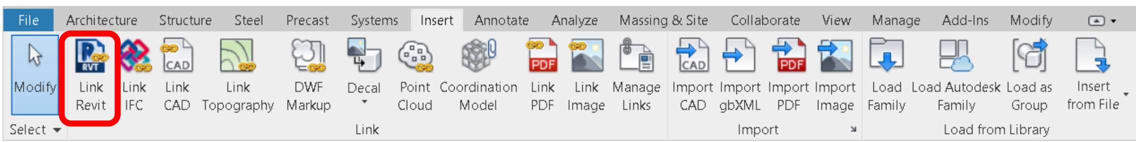


Figure 83 – Link Revit tool

To ensure that link models maintain their coordinates relative to the active model, linked models must be pinned in place. To pin all the linked files at once, click on any linked model in the Project Browser using the right mouse button, and then choose "Select All Instances" ► "In Entire Project". Then use the Pin tool from the Modify ribbon to pin the linked models to their current positions.

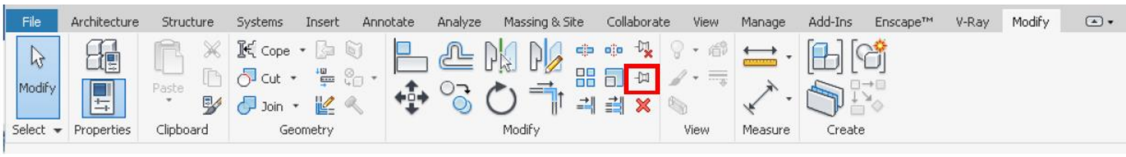


Figure 84 - Pin tool under the Modify tab

A federated model should be maintained in a manageable model file size as it can become slow to work with. The federated model must include the main model and necessary linked models. All models must open independently without opening error. When there is a link to a file that is not required in the final deliverable, the modeler must unlink and unload it before submission.

7.2.4.2. Modelling Guidelines

The project participants should fully implement industry- and software vendor-identified best practices and workflows for all aspects of modelling. These include, but are not limited to, the use of 3D geometry to represent physical features of project and facility components and elements, the use of relevant object categories when feasible, the addition of sufficient attribute information to elements, following proper naming conventions for all levels and types of data and metadata, and setting up shared resources and parameters to enable automatic display or extraction of model information to other formats (e.g., schedule or tabular formats) (NIBS, 2017).

Picture below illustrates an example of typical model progression across project phases.

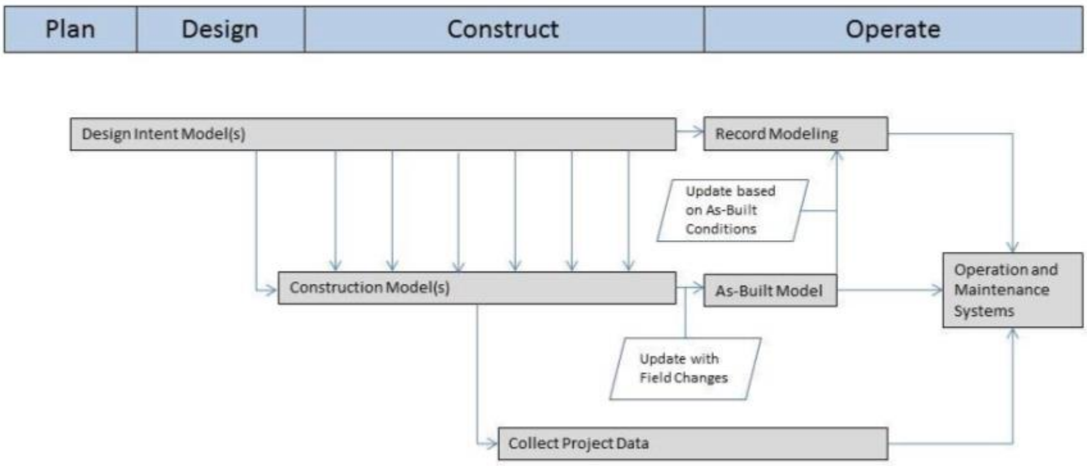


Figure 85 - A sample process for lifecycle model requirements (NIBS, 2017)

Project BIM Team members should use BIM applications and software to develop and document the project. Design professionals should create the Design Intent Model(s) and use them to produce accurate construction documents. Construction experts should design the Model using the Design Intent Model(s) and the construction documentation as a starting point (s). Similarly, as the Construction Model(s) evolve through the construction process, they serve as the foundation for Project Data (which frequently includes tabular or textual data). Also, during construction, the various Construction Model(s) combine to develop an As-Built model that captures more-detailed construction conditions (e.g., trade-specific fabrication models). As the project develops, the As-Built Model— along with the continual stream of project correspondence and information back to the Design professionals—facilitates the update of the Design Intent Model(s) into a Record Model. The construction model typically has highly detailed components that are not always an efficient source of information for operations and maintenance; hence the Record Model is developed from the Design Intent Model to provide a lightweight model. In general, the Record Model, along with the As-Built Model and Project Data, provides facilities management personnel with varying degrees of information in multiple formats to best support FM uses and activities (NIBS, 2017).

This BIM Guide groups the modelling guidelines by Architectural, Structural and MEP disciplines. This section outlines the requirements for the discipline teams to produce the building information models for the projects.

Each element will be modelled in relation to its size, shape, location, orientation, and quantity in general. During the early stages of a project, elements are generic and approximate; but, as the project advances, the elements' precision improves, and they become more specific.

7.2.4.2.1. Architectural Modelling Guidelines

- Model the architectural elements to a level that defines the design intent and accurately represents the design solution. The BIM Execution Plan should include all the details and responsibilities for meeting these modelling standards.
- The model elements shall include the information and data available at each stage.
- The building or feature elements shall be created using the appropriate software tools and components for walls, slabs, doors, windows and others.
- For each floor level of a project, building or feature elements must be modelled separately.
- When elements are smaller than the agreed-upon size, 2D lines and symbols can be utilized in the model. Some elements, such as those less than 50mm, may not require modelling.
- Building Elements must be modelled separately for each storey.
- The structural model should be utilised as a reference in the architectural model to avoid duplication of building elements.
- Architectural modelling is implemented in the following stages: Conceptual, Preliminary Design, Detailed Design, Construction and As-Built. The kind of models created at each stage are determined by the specified BIM deliverables.

7.2.4.2.2. Structural Modelling Guidelines

- The structural engineer shall carry out the modelling at each stage of the project and level of development of the elements produced at each stage will be specified in the BEP. The structural engineer may create an analysis model and a physical model with actual member sizes and positions.
- The building or feature elements must be made with the proper tools (Wall tool, Slab tool, etc.). Other relevant objects must be employed to construct the required building elements if the

features of the BIM authoring tool are insufficient for modelling the element. In this case, double-check that the element's "Type" is set correctly.

- A Structural BIM may contain all load-bearing concrete, wood, and steel structures, as well as non-load-bearing concrete structures.
- When elements are smaller than the agreed size, 2D or 2D standard details can be used in the model. Some elements smaller than 50mm, for example, may not require modelling.
- 2D can be used for loading plans.
- Building Elements must be modelled separately for each storey.
- Structural models may not be required at the concept or feasibility stage of a project.
- The structural engineer may supply alternative framing possibilities as sketches for the architect to analyse alternative design layouts for different massing models for new building projects.
- The structural engineer may create an initial model from record drawings for existing buildings. As part of a survey, the as-built model can be verified on-site.
- Structural modelling is implemented in the following stages: Conceptual, Preliminary, Detail, Construction and As-Built. The types of models produced at each stage depend on the BIM deliverables required.

7.2.4.2.3. MEP Modelling Guidelines

- The building services engineer shall carry out the modelling at each stage of the project and level of development of the elements produced at each stage will be specified in the BEP. The building or feature elements shall be created using the correct tools (ductwork, pipe work etc.).
- Building Elements shall be modelled separately for each storey or floor level.
- When the elements are smaller than the specified size, 2D drawings or standard details might be used to supplement the BIM model. Modelling is not required for elements less than 50mm.
- 2D drawings with standard annotations may also be used for schematic diagrams.
- Building Services models may not be required at the concept or feasibility stage of a project.
- The building services engineer may supply mechanical, electrical, plumbing & drainage, and fire protection choices as sketches for the architect to evaluate alternative design layouts for different massing models for new building projects.
- For existing buildings, the building services engineer may develop an initial model from record drawings. The as-built model may be verified on site as part of a survey (CIC, 2015).

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8. CONCLUSION

Validation- Final Presentation for BIMMS Board and Professionals

Having conducted the first and second validation points, namely the interview (Section3.2) and the questionnaire (Section 3.3), the BIM Guide was developed and modified based on the received comments. This section addresses the third validation phase of the dissertation which is the presentation of the final output of the work to the BIMMS professionals at the end of the dissertation process. The goal of this validation phase was to present the final work to the partner company and to gain validation in the professional environment. The last step of the validation process was in the form of a meeting with the same people from the first meeting, the board and one of the BIM Managers of the BIMMS company. The duration of the meeting was 1 hour and twenty minutes, and with the consent of the interviewees, it was recorded for further analysis. The structure of the meeting was as follows:

- Review of the research workflow;
- Presentation of main structure of the BIM Guide;
- Presentation of some extracts from the BIM Guide;
- Receiving feedback

After reviewing the process of the development of the BIM Guide, the second part of the presentation began with the explanation for the main structure of the dissertation. After that, the extracts from different sections of the Guide and some tables and workflows related to each topic were also presented. After presentation, the BIMMS professionals expressed their ideas, raised questions, and provided suggestions for future developments.

There were a few comments for the last-minute improvement that were applied by doing small changes to some parts of the work. However, all the comments received about the developed document were positive and encouraging. The board emphasised the fact that the guidance document should contain a variety subjects, most of them interrelated, and changing constantly due to the regulations which make it difficult to develop. However, they were impressed by the extensive work that has been done to develop such a complete and well-structured BIM Guide, and they congratulated on the accomplishment of developing a comprehensive and robust document.

The presentation to the BIMMS company validated the work in the professional environment since the BIMMS board members unanimously expressed their approval and satisfaction with the result.

Final Remarks

The objective of this dissertation was to conduct an extensive review of BIM guidance documents developed by universities, organisations, and government institutions and incorporate the different experiences to create a set of formal guidelines for BIMMS company for the efficient practice of BIM in its projects. The plethora of BIM guidance documents with disparate requirements published by various organisations can result in confusion among architects, engineers, and builders. The proposed BIM Guide can be utilised in projects to reduce the potential confusions. It can also improve the consistency of BIM implementation in collaborative design processes and the quality of information flow and BIM outcomes for all project actors. The BIM Guide document is the best method to familiarise the newbies to the BIM processes and framework in the organisation.

To achieve a well-structured and comprehensive BIM guidance document that is applicable to the daily practice of BIMMS company, an extensive literature review has been conducted. More than 100 BIM guides was reviewed and 19 of them were selected for detail review based on some criteria. To analyse the resource, 17 topics were chosen to discuss the guides over them. These topics are the topics that are covered in many of the BIM guides and they are significant to the company BIM application. The inclusion of all the range of subjects from strategic to more technical was another criterion that was considered during the topic selection.

The 19 BIM guide resources were analysed over the 17 topics in a comparison matrix. In this matrix (Table 2), each topic that is covered in a specific guide is given a score of 1. 3, or 5 in relation to the fact that how comprehensive and detailed this guide covers the topic. If the topic is just mentioned the score of 1 was given to it and if it is explained and elaborated the sore of 5 was given to the topic. Finally, the frequency of the topics- how many of the 19 reviewed guides cover each topic- and their level of specificity in the guides were illustrated and discussed.

To categorise the topics and develop a BIM guide document, the 4 knowledge clusters of Policy, People, Process, and Technology were chosen. This taxonomy originates from several studies by Succar (2009) and others. To place each topic into the pertinent category, two methods was implemented (Table 4), as well as exploiting the previous research works on this subject. Classifying the topics and sub-topics, main structure of the document has been prepared to be validated by the company.

The BIM Guide proposal was validated in three stages by collecting feedback from the potential users of this document. The meeting with the BIMMS board and the online questionnaire that was distributed among the BIMMS employees have been the two ways to validate the primary structure and content of the proposal and to receive the professionals' opinions on how to improve the document. The comments and suggestions received during the meeting and the online questionnaire have been analysed and many of them were applied to the BIM guide and that results to some changes and modifications in several parts the documents. The final content of the BIM Guide proposal has been developed through the study of study of hundreds of resources and it was prepared and presented to the board of BIMMS for the final validation. During all the validation points, the developed work was approved with tremendously high percentage of positive feedback. In general, the comments received from the BIMMS company professionals have enriched the work and validated it professionally.

Finally, the first edition of the company BIM Guide is presented in four chapters inside this dissertation.

Since BIM toolsets and uses constantly evolve, the BIMMS BIM Guide is intended to be reviewed and updated on a regular basis to keep up with the advances in industry technology, methodology and trends.

This dissertation achieved a handbook that gathered disperse information across the literature to propose a simplified guide for people working in BIM in organisations. This guide can be applicable to any organisation practicing BIM to enhance their knowledge of BIM and its processes.

Future Developments

Considering the limitation of the dissertation for the number of pages, only key information about each topic is discussed in the documents so that the topics can be more expanded for future studies.

Since the recommendations and instructions provided for the BIM operational areas in the proposed BIM Guide is based on Autodesk Revit software, further customisation with different software and platforms is recommended for future studies.

Preparing a BIM Execution Plan document tailored to the company requirement could also be an area of investigation for the future research.

The BIMMS board also suggested two areas for future research:

- Propose guidelines for intelligent ways of design reviews, design coordination, and construction support.
- Propose a system for organising clash detection process and speeding up the process of checking the clashes.

Due to the continuous advancements in construction industry, the guidelines provided by the current BIM Guide require periodic review and adaptation.

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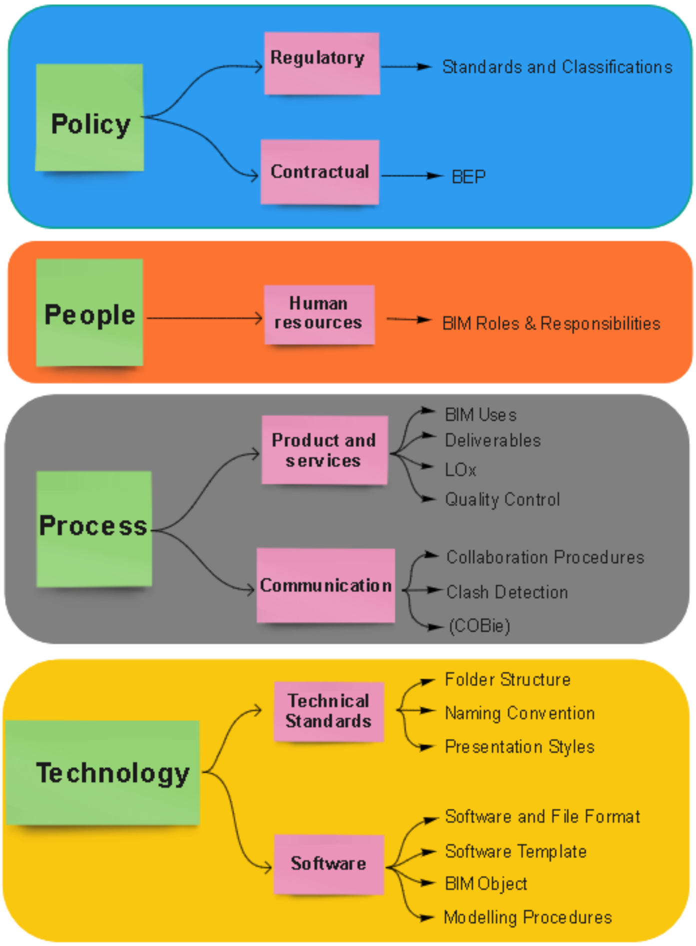
LIST OF ACRONYMS AND ABBREVIATIONS

AEC	Architecture, engineering, and construction
AECO	Architecture, engineering, construction, and operation
AIM	Asset Information Model
BCF	BIM Collaboration Format
BEP	BIM Execution Plan
BIM	Building Information Modelling
BIMMS	BIM Management Solution
BS	British Standard
BSI	British Standard Institution
BxP	BIM Execution Plan
CDE	Common Data Environment
COBie	Construction Operations Building Information Exchange
EIR	Exchange Information Requirements
IFC	Industry Foundation Class
ISO	International Organization for Standardization
GIS	Geographic Information System
LOD	Level of Development/ Detail/Definition
MEP	Mechanical, Electrical and Plumbing
NBS	National Building Specification
OmniClass	American Construction Specifications Institute
PAS	Publicly Available Specification
PDF	Portable Document Format file
RACI	Responsible, Accountable, Consulted, Informed
RIBA	Royal Institute of British Architects
Uniclass	British unified classification system
WIP	Work In Progress
XML	Extended Markup Language

APPENDICES

APPENDIX 1: THE STRUCTURE OF THE BIM GUIDE PRESENTED IN THE VALIDATION MEETING

Policy		People	Process							Technology						
Regulatory	Contractual	Human resources	Product and services				Communication			Technical Standards			Software			
Standards and Classifications	BEP	BIM Roles & Responsibilities	BIM Uses	Deliverables	Lox	Quality Control	Collaboration Procedures/ CDE	Clash Detection	COBie	Folder Structure	Naming Convention	Presentation Styles	Software and File Format	Software Template	BIM Object	Modelling Procedures



APPENDIX 2: THE BIM GUIDE TABLE OF CONTENT PRESENTED IN THE VALIDATION MEETING

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2.2. Contractual

2.2.1. BIM Execution Plan

2.2.1.1. BEP Requirements

2.2.1.2.BEP Template

3. People

3.1. Human resources

3.1.1. BIM Roles & Responsibilities

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5.2.2.8. Hatches Filled Regions

5.2.2.9. Title blocks

5.2.2.10. View templates

5.2.2.11. Phases

5.2.2.12. Materials

5.2.3. BIM Object

5.2.3.1. General Requirements

5.2.3.1.1. Definition of BIM Objects

5.2.3.1.2. BIM Objects' information

5.2.3.2. BIM object creation

5.2.3.2.1. Pre-existing objects

5.2.3.2.2. Linear infrastructure objects

5.2.3.2.2. Architectural objects

5.2.3.2.3. Structural objects

5.2.3.2.4. MEP objects

5.2.4. Modelling Requirements and Procedures

5.2.4.1. Project Setup

5.2.4.1.1. Model Coordinates and Orientation

5.2.4.1.2. shared coordinates

5.2.4.1.3. Model Scale & Unit

5.2.4.1.4. Levels

5.2.4.1.5. Grids

5.2.4.1.6. Model Division

5.2.4.1.7. Federated Model

5.2.4.2. Discipline Specific Guidelines

5.2.4.2.1. Architectural Modelling Guidelines

5.2.4.2.2. Structural Modelling Guidelines

5.2.4.2.3. MEP Modelling Guidelines

Annexes

APPENDIX 3: THE QUESTIONNAIRE RECEIVED COMMENTS

Question 1
This type of document is the only way to ensure a proper organization for any company working with BIM methodologies. Furthermore, provides a good workflow and facilitates essential tasks.
Standardize procedures and structural organization, which will ease the introduction of newcomers to an ongoing project, understanding every time what was done, how was done and how to establish the goals going forward.
I think it's important to have a knowledge of the responsibilities of each figure, of the objectives and good practises, in order to have a better vision of the whole BIM process.
BIM Guide allows standardizing processes, internal and external communication, important in the company's strategy to achieve objectives and add value to the customer. This document will allow aligning the company's image among owners, employees, leaders, shareholders and customers.
I truly believe in formal processes and standards. It is very important to have a formal workflow with guidance and standards to generally follow in the projects that we are involved.
A BIM Guide would, definitely, be a great help to standardize workflows and to guarantee quality overall.
I think there is more of 1 way of learning and acquire BIM skills. Personally, everything I learned since my first contact with BIM was from work colleagues, and I would like to have a written guideline to follow and even compare as I go through my learning process.
This guide would be very helpful. I feel the need to have some guidelines about the model setup, people's roles, drawing templates, annotation typical standards, etc.
We need to acquire the best experience and procedures of others. For sure we can aggregate value in each document.

Question 2
It seems all fine. But eventually, the Cobie column could stay as optional, since that if the Project BEP doesn't require, the Cobie information it might be not filled on the modelling process, until is required.
It would be important to include under the technical standards a "Volume Strategy" to understand better the project subdivisions (models, documents, etc...).
More emphasis on the modelling procedure in MEP
This categorization is well defined. Nothing to add.
I think this is a good sample. But a more explained step of presentations styles could be useful to identify patterns and standards to be used in the drawing production, for example. This is something that can be, in a certain way, standardize based on the Design Framework from BSRIA, for example.
A BIM should be an ongoing process, continuously being upgraded based on the users feedbacks.
No, these topics seem very good to me.
There will always something extra to add, but it looks like a great set to start with.
I think this categorization systems is very intuitive and self-explanatory of the order of the topics to have in consideration during the BIM process.
Perhaps add one topic related with R&D.
I find it clear like it is. Nothing to add
1- Policy *Comment: (ok)* *2- People* *Comment: Would recommend in adding addition sub-sections, namely competency requirements.* *3- Process* *Comment:* *- Would use a different designation for 3.1 Product and Services. This is not related with product,*

this is related with the execution strategy. I would recommend calling 3.1 Execution Strategy - Would recommend adding a section called Data Management or included it under 3.1.3. This is the section that details the management of information parameters to permit BIM uses and re-utilization of information within the model. - 3.2.3 - COBie. I would recommend indicating "COBie and others". These are all frameworks that are driven by employer engagement. - 3.2 - There are more subsections that can be added under 3.2. communication. E.g. Model Segregation strategy / Model Exchanges & Data Drops Protocols / Review Procedures 4- Technology - 4.2.4 - Modelling Procedures. This should be changed to section 3. Process > 3.1 The above are the key items, however there are a couple of subsections missing however the global picture is adequate.

Question 3
Looks well organized.
This is something that is evolving all the time that shall be updated time to time.
I think Engineering Analysis should be on the Plan phase.
No 21 and 22 could be increased into the construction phase as well, so the recording parameters could be thought on how to be included on the process.
"Shouldn't the Lighting and Sun Analysis be developed prior to the Energy Analysis? Wind analysis could be added."
I'm not sure what the n.14 is for. At construction phase, we are using some of the models to help show/solve some issues/RFI. I don't know of this can be considered part of use n.13, or if it could be interesting to add one more use of ""RFI/support.
It seems to me that all BIM Uses have their due importance.
Prefabrication Production.
"I would add to this list two specific uses in construction: BIM Supply Chain and Contracts management (associate to Procurement). And equipment management: equipment monitoring and preventive maintenance at manufacturing and construction phase."
Of course that there are certain uses that we do not use most of the time in most of the projects; but still it is important to list as you did.
Looks complete.
BIM Use missing - "As-Built info" - eventually consider here the activities needed to validate as-built models, such as Point Clouds from laser scanning.
Space Management an asset management should be also in plan and design. Most of the cases the investor needs in an early stage to ensure his investment.
"Would recommend adding the following: - Analytics, BIM to Field, Snagging, Augmented Reality"

Question 4
Eventually the handover process could not include the Cobie database enabled by default if it's not previously included on BEP documents at some stage.
I think this list of deliverables is adequate.
"3D scanning - point clouds, are always helpful for the existing condition model. Shop drawings at the Technical design stage, prior to points 9, 10, 12 and 13 look a bit premature. I would suggest 2 drawings faces, design intent drawings and shop drawings at the end of the technical design stage."
In my opinion, we can change the name "final models" to "construction models"; these models could not be the "finals", once that something in the field could make the Construction Manager to change some solution. I think the final model is only the as-built one (stage 6).
Point Clouds are missing (or from the existing conditions or even the ones produced after the new construction is done and to be used to validate As Built models)

in my opinion COBie Data is not necessary because IFC should resolve it
It seems complete. Nothing to add.
"Would recommend reviewing the standard deliverables of the RIBA plan of works. There is repetition in terms of deliverables from stage to stage 3- Spatial Coordination (Should be (Include: Drawings / 3D Coordination Reporting / Energy Analysis / QTO)"
I would say it looks complete.

Question 5
Well stablished construction tolerances that need to be included on coordination process. An 0mm tolerances / clash free modelling with 0mm tolerances could be impractical to archive in shorter times.
I Would Suggest a third party quality check for clash detections.
We need to clarify and to input the priority matrix of the project. We need to feed the workflow with this matrix in order to allow the BIM Authors to understand when they are required to act and when they are required to report.
"I would flip it, to make the BIM manager role the first (when reading from left to right), because, for clash detection process, the first step would be running a first clash test, identify all clashes and, after that, issue to each disciplines their correspondent activities. I would also question if the clash detection activity shall be performed by the BIM Manager of if it should be done by the BIM Coordinator."
Major design changes should be continuously reported by each discipline to the others or by the bim coordinator to each discipline.
Globally I would say the workflow should look like this.
No, seems perfect as it is.
The workflow should have the project coordinator so he can prioritize disciplines defines who needs to change
In general terms the process is correct. This shall need to be adapted from project to project.

Question 6
I think it should be added a step in the data check resorting to the search of the project missing items (pieces of containment, etc...).
The standards checks needs to be well coordinated with different countries requirements on those guidelines.
Site checks are indispensable, essentially for structural builders works.
I think there should be a Quantity Check: define the schedule layout and the process of quantity extraction.
I think the table is at least good. However, in my experience, we need to attribute a huge importance to the model coordination. It is through the navigation through the model that we are going to ensure the compliance with the standards and principles of the project.
Quality control might also need to include any optimization process, in order to guarantee the most efficient and cheap solution
"I don't think that every drawing or schedule should necessary be extracted from the model.
For bigger projects I would probably add a check related with the overall health of the model."
Would recommend after or at the same time visual checks performing standards check (engineering / BIM) standards.

Question 7
Stablished coordination paths and rules to previous guidelines to coordination process.
"I don't get this scheme well. The idea is to indicate the ways in which the team collaborate and communicate? It seems to me that the 3 elements have different purposes, maybe the purpose could be associated to each of them."
We can think on How we can use collaborative data to provide trustful information to the BIM Managers about productivity, progress valuation and quality control.
In general terms this is correct.

Question 8
Eventually No 3 units template could not be needed in start process.
Plot styles settings
Organization and List of Shared/Project Parameters
Families Template.
Shared Parameters.
No, this proposed templates encompasses everything
Naming convention also important.
There are a lot of elements that are used across multiple projects, such as families, project and shared parameters. These are an example of what should be included in a template.
Pipe Systems and Duct Systems
File Naming Conventions, Data Parameter Standard, Family Content Convention

Final Comments
BEP can be a powerful tool when it is understood by everyone, which means when all functional areas of the company are involved in it – marketing, human resources, IT, finance, operations, research and development, etc. It is also important to think about the strategy for its implementation, so that employees identify it as a process that facilitates their work and not a list of obligations that they have to fulfil in their work routines. Whenever possible, it is interesting to go deeper into automating processes, creating platforms and structures that facilitate the workflow between all stakeholders.
Important to guide through most relevant technical standards to be followed (American, British and German).
I think that besides all information, procedures, standards, and templates, the bim guide could contemplate very practical things.

APPENDIX 4: BIM ROLES IN REVIEWED BIM GUIDES

Guides \ Roles	Project Manager	BIM Manager	BIM Coordinator	BIM Modeller	Owner	Lead Consultant	Contractor	CAD Manager	Information Manager
New York		•	•						
Singapore		•	•						
FIU		•	•		•				
Massachusetts		•	•	•					
Massport		•	•						
AEC (UK)		•	•	•					
CIC		•	•	•		•	•	•	
NATSPEC		•	•				•		
Russia		•	•	•					
NBGO		•	•						
PANYNJ			•	•					
Rail Baltica		•	•						•

APPENDIX 5: RACI MATRIX

Role	Deliverable																								
	Concept Model	Architectural Model	Structural Model	MEP Model	Architectural Schedules Quantities Details Costs	Structural Schedules Quantities Details Costs	MEP Schedules Quantities Details Costs	Provide Specific Model Objects	Object's Library	Clash Detection Architectural Model	Quality Assurance Architectural Model	Clash Detection Structural Model	Quality Assurance Structural Model	Clash Detection MEP Model	Quality Assurance MEP Model	Clash Detection Federated Model	Quality Assurance Federated Model	Validation Federated Model	Clash Detection Federated Model for Submission	Quality Assurance Federated Model for Submission	Validation Federated Model for Submission	Clash Detection Federated Model for Construction	Quality Assurance Federated Model for Construction	Validation Federated Model for Submission	Shop Drawings
Client/Owner	C	I																I			I			I	
BIM Consultant										I	I	I	I	I	I	I	I		I	I		I	I	I	I
BIM Manager (Architect)	I	I	I	I	I	I	I		A	I	I	I	I	I	I	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A
BIM Coordinator Architects Task team		C			A				C	A/R	A/R					C	C	I	C	C	I	C	C	I	R
Architect Designer Team Leader	R	A	C	C						I	I					I	I		I	I		I	I		
BIM Modeller Architects Task team		R			R					C	C														
BIM Coordinator Structural Engineers Task team			C			A			C			A/R	A/R			C	C	I	C	C	I	C	C	I	R
Structural Engineer Team Leader		C	A	C								I	I			I	I		I	I		I	I		I
BIM Modeller Structural Engineers Task team			R			R						C	C												
BIM Coordinator MEP Engineers Task team				C			A		C					A/R	A/R	C	C	I	C	C	I	C	C	I	R
MEP Engineer Team Leader		C	C	A										I	I	I	I		I	I		I	I		I
BIM Modeller MEP Engineers Task team				R			R																		
Contractor Main																						C	C	I	R
Sub-Contractor																						C	C	I	R
Facility Manager		C	C	C																		C	C	I	R
Supplier 1								R	R																
Supplier 2								R	R																

R Responsible = Assigned to complete the task or deliverable.
A Accountable = Has final decision-making authority and accountability for completion. Only 1 per task.
C Consulted = An adviser, stakeholder, or subject matter expert who is consulted before a decision or action.
I Informed = Must be informed after a decision or action.
A/R Accountable and Responsible